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THE LOUISVILLE AIR POLLUTION STUDY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

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THE LOUISVILLE AIR POLLUTION STUDY

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1961

THE LOUISVILLE
AIR POLLUTION STUDY

A Technical Report on the Joint Study of Air Pollution in Louisville and Jefferson County, Kentucky, 1956-57

Prepared by Staff
of the Participating Agencies

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Air Pollution

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1961

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The Robert A. Taft Sanitary Engineering Center is a national laboratory of the Public Health Service for research, training, and technical consultation in problems of water and waste treatment, milk and food safety, air pollution control, and radiological health. Its technical reports and papers are available without charge to professional users in government, education, and industry. Lists of publications in selected fields may be obtained on request to the Director, Robert A. Taft Sanitary Engineering Center, Public Health Service, Cincinnati 26, Ohio.

THE SPECIAL AIR POLLUTION STUDY OF LOUISVILLE AND JEFFERSON COUNTY, KENTUCKY, 1956-1957

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PREFACE

The Special Air Pollution Study of Louisville and Jefferson County, Kentucky was conducted during 1956 and 1957. A summary report of study results entitled "The Air Over Louisville" [39] was published in May 1958. The purpose of this present report is to give a more detailed account of the study and to furnish additional results of data analyses made since publication of the summary report. The present report reflects conditions existing at the time of the study. Since that time, some recommendations made in the summary report have been implemented. Some changes have been made in industrial and other activities which changed the nature and extent of pollution emissions.

NOTE

Mention of specific commercial products does not imply in any way endorsement of these products or recommendation of them over similar commercial products by the agencies participating in the study.

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Btu	British thermal unit
cfm	cubic feet per minute
°C	degrees Centigrade
°F	degrees Fahrenheit
l	liters
lpm	liters per minute
MSL	Mean Sea Level
mph	miles per hour
μ	micron
μg	microgram
mg	milligram
ml	milliliter
$m\mu$	millimicron
mm	millimeter
$\mu g/m^3$	micrograms per cubic meter of air
ppb	parts per billion by volume
ppm	parts per million by volume
Time of day	reported on the basis of a 24 hour clock. e.g. 6 A.M. is 0600; 3 P.M. is 1500; midnight is 2400; and noon is 1200. Central Standard Time unless otherwise noted (CST).
$>$	greater than
$<$	less than
$\geq$	equal to or greater than
$\leq$	equal to or less than

THE LOUISVILLE AIR POLLUTION STUDY

CHAPTER 1

INTRODUCTION

Louisville, Kentucky, like many other American cities, has experienced an increasing urban air pollution problem associated with population and industrial growth. Before World War II major concern was directed toward smoke and fly ash from domestic, commercial, and industrial coal combustion. The war and postwar years witnessed a shift in major concern to a more heterogeneous type of air pollution involving a variety of gases, fumes, dusts, and odors characteristic of an urban complex.

When the supply of natural rubber for American industry was cut off during World War II an intensive program of synthetic rubber production became necessary. Louisville was chosen as one manufacturing site, and in 1941 the first of a number of large plants for the production of chemical rubber was built in an industrially zoned area at the southwest boundary of the city. Additional plants followed and within a short time there was a dense network of plants producing synthetic rubber and its components. Other types of plants were added until today there are three synthetic rubber plants, a calcium carbide and acetylene plant, a butadiene plant, two electric generating stations, an aluminum pigment plant, an aluminum reclaiming plant, a plant producing chlorinated hydrocarbons and hydrochloric acid, a freon plant, a large railway crosstie creosoting plant, two oil refineries, and several petroleum storage installations. In the Louisville area, this industrial complex is known as Rubbertown (Figure 2-1).

In 1946, following an increase in public complaints, a Smoke Commission was set up to investigate and report on the problem of smoke from industrial stacks and apartment house chimneys. In 1951, realizing that smoke is only one aspect of total air pollution, the commission was renamed the Louisville Air Pollution Control Commission and its responsibilities were expanded accordingly. Less than a year later the Kentucky legislature passed an enabling act authorizing establishment of county-wide pollution control agencies and in July 1952, the Jefferson County Air Pollution Control District came into being with jurisdiction over all incorporated and unincorporated areas within the county.

PRIOR AIR POLLUTION STUDIES

After World War II residents of West End Louisville complained increasingly of reduction of visibility, dust settlement, eye irritation, and odors. In 1950, in an effort to evaluate sources of pollution, the city contracted with the Institute of Industrial Research of the University of Louisville to conduct a study to determine the sources of dust frequenting western Louisville. This study indicated that a more detailed investigation would be necessary before definite conclusions could be drawn.

In the same month that the Jefferson County Air Pollution Control District was established, a group of Rubbertown industries contracted with Battelle Memorial Institute of Columbus, Ohio for a comprehensive survey of the West End air pollution problem. The resulting report[1] stated the following:

> "Because the program produced too few data to establish a source of pollutants, it is obvious that in order to reach incontrovertible conclusions, as to the cause and solution of the problem, an expanded program would have to be undertaken. This would involve not only an accumulation of a larger number of samples much more frequently at appropriate times, but also for some contaminants, means should be devised for taking much larger samples so that exhaustive chemical, spectroscopic, and x-ray diffraction studies could be made where necessary to identify completely the material collected..."

> **"To meet the need imposed by these growing problems the concept of the area-type air pollution survey has been developed. Such a survey considers not one plant but the whole industrial neighborhood and its relation to the community in which it is located."**

INITIATION OF THE SPECIAL AIR POLLUTION STUDY

Previous studies, in the opinion of the Jefferson County Air Pollution Control Board, were not sufficient to provide a basis for governmental action, to bring about control of existing problems. This being the case, Mr. Henry I. Fox, Louisville Attorney and Vice Chairman of the Air Pollution Control Board, in April 1955 wrote to the Honorable John H. Robsion, Jr., Representative from Kentucky's Third Congressional District, to obtain information on establishment of air pollution regulations "that are of benefit to the public and fair to industrial and other offenders." Mr. Fox's request was referred, through the Secretary of the Department of Health, Education, and Welfare, to the Air Pollution Engineering Research activity of the Public Health Service at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Soon after, in July 1955, Public Law 159 (84th Congress) was enacted, which authorized the Federal Government to participate in community air pollution studies. As a result, Mayor Andrew Broaddus of Louisville recommended that the Air Pollution Control Board of Jefferson County, sponsor a cooperative study involving the Board, the Louisville and Jefferson County Board of Health, the Kentucky Department of Health, and the U. S. Public Health Service. Participation of State and Federal agencies was desired in order that additional facilities and professional competencies could be brought to bear on the problem. Through the Public Health Service, technical support also could be made available from other Federal agencies such as the Army Chemical Corps, Corps of Engineers, Air Force, Weather Bureau, Bureau of Mines, and National Bureau of Standards.

On July 18, 1955, the late C. Saul Hertzman, then Chairman of the Board, and Ralph W. Bourne, Chief Engineer of the Board, met with Arthur C. Stern, Chief of Air Pollution Engineering Research at the Robert A. Taft Sanitary Engineering Center. The result of this meeting was a joint study proposal prepared by the U. S. Public Health Service, for consideration by all concerned. The proposal was subsequently accepted.

Air Pollution Engineering Research was asked to draw up a Memorandum of Agreement among the four participating agencies. A steering committee representing all four agencies held its first meeting on October 13, 1955, at the office of the Air Pollution Control Board in Louisville City Hall. The Memorandum of Agreement was accepted by all concerned. At the request of the Board, the Public Health Service appointed a Technical Director for the study. He was Dr. A. T. Rossano, Jr. Subsequently the Public Health Service designated Mr. Norman E. Schell, as resident engineer in charge of the study.

It was estimated that the study would cost approximately $150,000 per annum for two years. Approximately half of the funds were provided by the U. S. Public Health Service. Industry, through the Louisville Chamber of Commerce, provided $70,000. The remainder was provided by the City of Louisville and Jefferson County. Field investigations began in late 1955 and continued until the fall of 1957.

STUDY OBJECTIVES

Study objectives were set forth in the Memorandum of Agreement (Appendix A). The broad objective was to augment existing knowledge of the nature, sources, and extent of the air pollution problem in Jefferson County Kentucky (and primarily in western Louisville) as a basis for developing a rational program of control. Specific objectives briefly were as follows:

1. Prepare an inventory of air pollutants emitted to the atmosphere with special regard to major sources in western Louisville. 2. Determine the range of influence of pollutants arising in western Louisville. 3. Evaluate the effect of pollutants (especially odors and dusts) on residents of western Louisville and the effects of pollution on materials. 4. Obtain a detailed analysis of contaminants in the atmosphere and relate this information to pollution sources and to solution of the Louisville problem. 5. Determine the bacterial content of the air over Louisville.

STUDY ORGANIZATION

The Memorandum of Agreement provided for a Steering Committee composed of representatives from the four participating agencies. The functions of the committee were to review technical progress, provide information to the public, and advise the Technical Director on administrative matters. The Steering Committee met monthly and was otherwise available for consultation. Prior to the operational phase of the study, the Air Pollution Control Board, the Steering Committee, study personnel, and others discussed existing air pollution problems, study objectives, funds, and time limitations, and developed a detailed plan of activities.

A budget, prepared by the Technical Director, was considered and revised by the Steering Committee and presented to the Mayor and City Manager for review. After the budget was approved, a special fund for study expenditures was created to be administered by the fiscal department of the City of Louisville.

Field operations were controlled from study headquarters located at 4000 Michigan Drive (Figure 1-1). Twelve hundred square feet of floor space were utilized for offices, certain equipment maintenance, and sample analysis. A nearby garage provided space for vehicle storage, carpentry, and equipment servicing. Most of the air sample analyses were performed by study personnel working in laboratory space provided by the Louisville and Jefferson County Health Department.

The local staff was headed by a Resident Engineer responsible for administrative and technical aspects of the study. Full-time staff included an office manager, a sanitarian provided by the local health department, an Air Pollution Control District inspector, three laboratory chemists, one field chemist, one engineer, two meteorologists, one clerk-stenographer, and a technical consultant. Part-time personnel included a nurse provided by the local health department, an Air Pollution Control District inspector, two laboratory aides, two field sampling aides, and a meteorological aide.

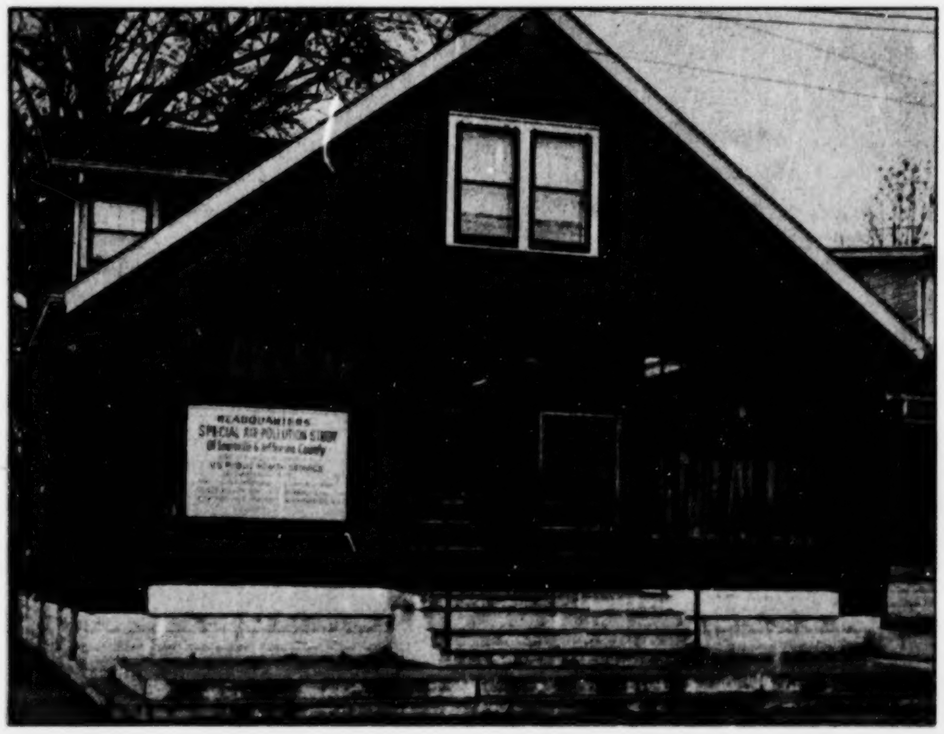


Figure 1-1. STUDY HEADQUARTERS

CHAPTER 2

STUDY ACTIVITIES AND METHODS

A wide variety of investigations were conducted to provide data needed to meet objectives of the study. These are described briefly in this chapter. Results of investigations are given in chapter 3. Further details are given in appendices B through E.

POLLUTION SOURCE STUDIES

An inventory of pollutant emissions was made by source sampling and analysis and by estimation based on existing emission information, combined with a knowledge of process throughputs, fuel consumption, and similar data. The source study was limited to the Rubbertown-West End area, i.e. western Louisville.

In general, sources were considered as multiple, such as transportation or domestic heating, or specific, such as individual industrial processes. In this study three general types of sources were considered in detail: 1) industrial, 2) transportation, and 3) domestic, and commercial. Additional sources such as municipal incineration of trash, commercial use of solvents, and others, were not included in this survey because of their minor contribution or inapplicability to the problem in western Louisville.

Industrial Source Sampling

The management of each industrial plant in the Rubbertown area was advised of the survey and its objectives. This led to cooperation with management in every case. A preliminary plant survey was made to determine the source sampling necessary to estimate the nature and extent of each main source of atmospheric pollution. The complexity of this initial survey depended on the size and type of the industrial process.

Particulate samples were obtained from major sources using a variety of techniques, including paper thimble samples (Whatman, 43 x 123 mm.), high volume samples (type "S" filters), electrostatic precipitator samples, and membrane filter samples (Millipore type AA, 47 mm.). Details on the use of such sampling equipment may be found in the literature. 2/

Gas sampling methods included grab sampling, continuous freeze-out sampling, and use of fritted glass absorbers. The grab sampling method, developed during the study, 3/ made use of an evacuated two-liter flask for collection of samples from both cyclic and continuous emissions. The freeze-out sampling method made use of a trap immersed in liquid nitrogen preceded by a condenser for moisture removal. Use of this equipment was limited to steam jet discharges. Total sample volume was measured using the weight of moisture condensed and relating this to the temperature and pressure of the steam discharged. Fritted glass absorbers were used for sampling of sulfur dioxide and sulfur trioxide, using the technique of Johnstone and Taylor. 4,5/

Analytical work on the grab and freeze-out samples collected by study personnel was performed by the National Bureau of Standards 6/ using mass spectrometry. Fritted glass absorber samples were collected and analyzed by U. S. Bureau of Mines personnel. 7/

Results of stack gas analyses were used in calculating total weight of emissions, using discharge volumes and process data supplied by the individual companies.

In many cases industrial pollution arose from processes from which emissions were not confined to a stack. When reliable estimates of these losses could not be made on the basis of process data and calculations, special samples were taken.

Evaporation Losses from Impregnated Wood Storage.

One plant in the Rubbertown area treats wooden ties with creosote preservative and subsequently stores them in the open for a year to dry. During this period, volatile creosote vapor (primarily m-cresol) escapes to the atmosphere. In order to evaluate emissions from this source, borings were taken from ties which had been exposed to the atmosphere for varying periods. These borings were analyzed for total volatile content using a steaming technique. [6] A calculation of total volatile loss for a year was made.

Evaporation Losses from Volatile Liquid Waste Discharges.

In the process of acetylene manufacture used by a Rubbertown plant, large quantities of an acetylene-bearing slurry are discharged daily into a tailings pond. Acetylene hydrogen sulfide, and other gases are evolved and escape to the atmosphere. To estimate the loss of acetylene, grab samples of slurry of various ages were taken and analyzed using spectrophotometric and mass spectrometric methods. [6] Based on slurry analyses and process data total weight of escaping acetylene was calculated.

Hydrogen sulfide evolution was calculated on the basis of relative concentrations of acetylene and hydrogen sulfide in freeze-out samples of the atmosphere over the slurry pit. These relative concentrations and the rate of escape of acetylene, calculated as described above, were used to compute the rate of escape of hydrogen sulfide.

Estimation of Industrial Process Emissions

Many sources of industrial pollution are not readily appraised by stack or other samples. However, use of related information including process data often permits good estimates of losses without the necessity of sampling. Estimating methods described in the following sections were used in the Rubbertown source inventory.

Losses from storage tanks. Losses from storage tanks can account for 25 per cent or more of the gaseous emissions from certain types of industry, e. g. petroleum refining and gasoline distribution depots. Existing literature on the subject was reviewed and three general equations were developed (Appendix B) for estimation of losses due to vapor expansion ("breathing"), vapor displacement ("filling"), and boiling. The equations developed are generally applicable to any liquid in any size fixed-roof vessel in any climate, although the empirical constants were developed from experience in the petroleum industry.

For other than fixed roof tanks the factors developed by the American Petroleum Institute (Appendix B) were used.

Losses from open basins. Volatile liquid mixtures are often stored in open ponds either to separate solids by settling or to recover valuable products by flotation. Three plants in the Rubbertown area use such techniques. In open storage a large quantity of volatile material may be lost by evaporation. To estimate this loss calculations based on mass transfer by convection were used [8] (Appendix B).

Process losses in petroleum refining. In the petroleum refining industry much work has been done in determining emissions as a function of process throughput quantities. Table 2-1 presents a partial list of estimating factors determined largely from extensive source sampling in the Los Angeles area. [9] In choosing factors for preparation of Table 2-1, specific process information was used wherever possible. Thus, for example, emissions from boilers and process heaters (item 8) are based on actual fuel consumption rather than on total refinery throughput (See also items 3, 5, 9).

The factors shown in Table 2-1 were used to estimate emissions from a refinery (plant number 5) in the Rubbertown area. Emissions of sulfur bearing gases were estimated using factors in Table 2-1 and a sulfur balance on fuel used for in-plant heating. This fuel consists of residual oil and gas from six process areas, the sulfur content of which is variable.

Losses based on material balances and other process data. Several miscellaneous methods were used to estimate process losses when results of source sampling were not available. Examples of these methods include: 1. Reactor ventings of process gases - estimates of losses were based on reactor volume, probable gas composition, temperature, pressure, and frequency of venting data supplied by companies. 2. Minor intermittent discharges from steam vacuum jets - estimates of losses were based on company estimates using material balances. 3. Products of combustion from chemical waste burners - estimates of losses were based on feed analysis, supplied by company, and assumed combustion efficiency. 4. Leakage from process equipment - estimates of losses were based on material balances supplied by company. 5. Low temperature, vapor-balanced storage of volatile liquids - estimates of losses occurring during gain in inventory were based on material balances supplied by company. 6. Gas absorber or scrubber effluents - estimates of losses were based on probable absorber or scrubber efficiency and feed composition, using data supplied by companies. 7. Effluents from air cleaning equipment for process solids - estimates of emissions were based on loading and collection efficiency data supplied by company.

Estimation of Emission of Products of Combustion from Industrial Plants

Products of fuel combustion represent the greatest single source of pollution, industrial or otherwise. It would have been unfeasible to sample every combustion effluent in the Rubbertown area for the large variety of gaseous and particulate pollutants emitted from each source. Consequently these pollutant emissions were estimated using the best available information and taking into account the type of fuel used, method of firing, fuel analysis, and total fuel consumption for each fuel burning operation. It is noted that individual emissions estimated in this fashion may be only rough approximations, since individual combustion operations vary widely. However, a sufficient number of operations are covered, the degree of accuracy in the total estimate should be improved. It is probably safe to assume that, on the basis of the reliability of the estimating factors and the estimates of fuel consumption, the total estimates of emissions from fuel combustion are accurate to within 25 to 50 per cent. Existing technical literature was reviewed to arrive at factors which are as applicable and accurate as possible. These factors are presented in Tables 2-2 and 2-3. The sources of information and methods of development of these estimating factors are presented in Appendix B.

It will be noted that all emissions are on the basis of a unit weight of fuel. These simplified calculations allowed a general comparison of the three main fuels in terms of total pollutant potential. In some cases it was necessary to use fuel analyses in estimating emissions. Thus for example, sulfur gas production was calculated on the basis of the sulfur content of the fuel and particulate emission from coal burning was estimated using the ash content of the fuel.

Certain gaseous pollutants for which no reliable estimating factors are available are listed using the term "n.a." (not available). The fact that certain gases are not listed as being emitted does not mean that they may not be emitted. In most cases, only principal emissions which have been reported elsewhere have been listed, with the result that total estimates are on the low side.

In making estimates of particulate emission from coal burning facilities which are equipped with air cleaning equipment, it was occasionally necessary to make use of published performance data or calculations based on air cleaning theory. For example, one large plant burns pulverized coal and partially collects the particulate effluent with multiple cyclone type collectors. In order to estimate size distribution in the final effluent, the data in Table 2-3 and collector performance theory were used. Using the Rosin, Rammler, and Intelmann derived relationship [10] for the minimum diameter particle completely separated from the gas stream and the dimensions and operating characteristics of the collector in use, the minimum diameter particle completely collected was determined. With this value and the appropriate value for particle size of the collector influent (Table 2-3) the effluent particle size characteristics were calculated. Similar calculations were necessary in another case where electrostatic precipitators were in use. In this case data from Table 2-3 were used in conjunction with the performance theory of Deutsch.[11]

Estimation of Emissions from Domestic and Commercial Sources

The domestic and commercial contribution to total pollutant load in the atmosphere can be considerable. This contribution arises principally from the combustion of fuels used for space and water heating, and for cooking.

It was obviously unfeasible to sample the effluents from each fuel burning operation. As was done for most industrial fuel burning operations, pollutant emissions were caluclated using the best available data on emission of combustion products and data on type of fuel, method of firing, fuel analysis, and fuel consumption. Factors used for estimating pollutant emissions (Table 2-5 and 2-6) were obtained from the literature as described in Appendix B. The same qualifications and limitations to use of these factors apply as in the case of the industrial emission factors.

In order to apply these factors to western Louisville, total use of coal by domestic and commercial (and a few small industrial) establishments was estimated. Total coal shipments into the Louisville area for 1956 were 2,145,960 tons of western Kentucky coal and 191,526 tons of eastern Kentucky coal, the later including coal from West Virginia, Virginia, and western Pennsylvania.[12] The 1,341,880 tons of western Kentucky coal burned per year by industries in Rubbertown was subtracted from these totals. The remainder was prorated on the basis of population (western Louisville has 17 percent of total Louisville population) to give an estimate of coal burned by domestic and commercial establishments in western Louisville (Table 2-7). About sixty per cent of this coal is used in hand-fired units and forty percent is used in stoker fired units.[13] Over three fourths of the coal is used in central heating systems and the rest in stoves. [13] Total pollutant emissions from coal burning were then calculated on the basis of data in Tables 2-5, 2-6, and 2-7.

The same general method was applied to emissions from fuel oil and natural gas combustion. The total non-industrial sales of No. 2 and No. 4 fuel oils for 1956 prorated to western Louisville amounted to 2,270,000 gals.[14] Data on natural gas consumption from the Louisville Gas and Electric Co., when prorated to western Louisville, indicate a non-industrial usage of 3.42×10^9 cu. ft.[15] These data (Table 2-7) when used in conjunction with the factors in Tables 2-2 and 2-5 provided the basis for estimating total pollutant emissions from fuel oil and natural gas combustion.

Estimation of Emissions from Transportation Sources

Exhaust gases and aerosols are emitted from internal combustion engines and fuel vapors are released in handling liquid fuels used for transportation activities. These emissions were calculated on the basis of estimating factors obtained from the literature and a knowledge of gasoline and diesel fuel consumption in western Louisville. Estimates of pollutant emissions from internal combustion engines are summarized in Table 2-8. These factors were developed from data appearing in the technical literature (Appendix B). Use of this method results in a precision of only about 25 percent because of inaccuracies in the factors themselves, possible wide variation in applicability, and errors in fuel consumption estimation.

Losses from fuel handling operations were also estimated on the basis of fuel consumption data. According to estimates based on data obtained in Los Angeles[16] gasoline vapors, primarily aliphatic hydrocarbons, lost through fuel handling operations amount to 0.104 lbs. per gallon of gasoline consumed. This emission arises from displacement losses in marketing (filling gasoline distribution trucks and service station tanks), in filling automobile tanks, and from gasoline evaporation from automobile tanks and carburetors. A similar type loss might be expected to occur in the handling of diesel fuel. However, because of the lower vapor pressure of diesel fuel, and the relatively small amount of fuel used, displacement and evaporation losses from the handling of such fuel are not of practical consequence.

Total gasoline consumption in western Louisville was determined in the following way. The total vehicular (auto and truck) registration for Jefferson County prorated to western Louisville (on the basis of population) was 33,300 vehicles.[17] On the basis of figures from the Kentucky State Highway Department [18] for average daily mileage per vehicle and average fuel consumption per vehicle-mile, this number of vehicles consumes 302,000 gallons of gasoline per day. In addition, gasoline-powered buses, operated by the Louisville Transit Co., consumed 250 gallons of gasoline per day [19] in western Louisville (1956). The total annual consumption of gasoline in western Louisville was therefore approximately 18.5 million gallons (1956) (Table 2-9).

Diesel fuel consumption was determined for buses [19] and diesel locomotives [20] operating in Louisville. The total consumption in 1956 was 7.4 million gallons (6.1 million gallons for diesel locomotives and 1.3 million gallons for buses). Prorated to western Louisville this consumption was 1.2 million gallons (Table 2-9).

Total pollutant emissions from internal combustion engines were calculated from the data of Tables 2-8 and 2-9. In most cases this consisted of multiplying corresponding factors. In the case of sulfur oxides emission from diesel fuel consumption a further refinement was made. The portion of fuel used for locomotives was assumed to be regular grade 20/ while that used for buses was assumed to be of premium grade. The appropriate factors for sulfur oxides production were then applied.

Gasoline vapor loss (hydrocarbons) from handling operations were calculated using total fuel consumption and the factor 0.104 lbs.per gallon of gasoline consumed.

TRACER STUDY

Seven air-borne tracer runs were made to demonstrate dispersion of pollutants arising in Rubbertown and the effect of stack height and meteorological parameters on dispersion. The tracer material, 21, 22, 23/ an extremely fine zinc-cadmium sulfide powder, was disseminated into the effluent of specific sources of pollution in Rubbertown. A network of air sampling stations in western Louisville was used to collect samples while the tracer was being released. From the amount of tracer material in the samples, a dispersion pattern was developed.

The behavior of zinc-cadmium sulfide in the atmosphere is reasonably indicative of dispersion of gaseous pollutants as well as fine particulates due to its small particle size (mass median diameter of two microns).

In order to demonstrate the desired dispersion effects with a feasible expenditure of effort tracer runs were made only when meteorological forecasts indicated that desired meteorological conditions would prevail. Criteria for favorable weather were that the wind through the lowest 1000 feet be from the south through west-southwest sector, and that there be no precipitation. The Weather Bureau Station at Standiford Field provided forecasts of wind direction, speed, and variability at the surface, 1000 ft., and 2000 ft., temperature and vertical temperature gradient, precipitation, and cloud cover. If conditions appeared favorable for a tracer operation, winds recorded at network sites were checked, the forecast monitored for changes, and the operation carried out if everything was in order.

Tracer material was released from the top of a 250 foot high stack or from a roof 50 feet above ground. Dispersion patterns obtained when tracer was released from the stack were presumed to be representative of dispersion from many of the tall stacks in Rubbertown. Dispersion patterns obtained when tracer was released from the roof were assumed to be representative of dispersion of discharges from low stacks, vents, monitor roofs, etc.

The tracer dissemination procedure involved release of a measured amount of tracer material at a constant rate over a period of approximately thirty minutes. Tracer material was fed into the inlet of a high speed centrifugal blower and thence discharged to the atmosphere, a mechanical device was used to feed tracer material into the blower at a uniform rate when tracer material was being released from the roof. However, limited space at the top of the stack did not allow use of the device. In lieu thereof, the total amount of tracer to be released was subdivided into a number of glass tubes. Contents of the tubes were successively fed into the blower intake by hand at as uniform a rate as possible over the appropriate time interval.

After several trials, it was found that about two pounds of tracer dispersed over a 30 minute period provided satisfactory results from the standpoint of providing a suitable amount of tracer material in air samples collected.

The air sampling network used for tracer studies consisted of 26 stations in western Louisville located about one-half mile apart on arcs approximately two, three, and four miles from the release points, Sampling was accomplished using a membrane filter 47 millimeters in diameter. Air was drawn through filters at a flow rate of about 12.5 lpm. All samplers were started just before the tracer was disseminated. The sampling period was governed by an estimate, based on meteorological data, of the time required for the last tracer material released to pass over the sampling station farthest from the release point. One-half hour was added to this to insure that the tracer had all passed. In general, air sampling was carried on for two hours.

Immediately after use, membrane filters were sealed in their holders with masking tape to minimize the possibility of contamination. In the laboratory, filters were cemented to two inch by three inch glass slides with thinned rubber cement. Mounted filters were exposed to ultraviolet light, causing the zinc-cadmium sulfide to fluoresce. Each fluorescing particle was counted, using 100 times magnification with a monocular microscope, equipped with a mechanical stage. The entire filter was scanned one field at a time. Results were reported as total number of fluorescent particles per filter. Used filter holders were cleaned with detergent to remove fluorescent material. Unexposed filters were assembled in holders, sealed in the laboratory to prevent contamination, and returned to the field in preparation for the next run. Even with these precautions, some contamination occurred. Contaminated filters were not analyzed.

METEOROLOGICAL STUDIES

Meteorological measurements were made primarily to determine patterns of air flow which transport and diffuse pollutants within and adjacent to the study area. This section provides a brief description of the measuring stations, instruments installed, and operation of instruments. Further details concerning study methods, procedures, and equipment, and more complete descriptions of instrument locations are given in Appendix C.

Meteorological Measurements Network

Past climatological records, primarily hourly wind observations made at Bowman Field and Standiford Field, were reviewed during the planning stages of the study. These records showed winds to be predominantly from the south and southwest. Existing knowledge indicated that topographic surroundings of Louisville tend to cause air flow to follow the ridge west of the Ohio River, thus increasing the frequency of local air flow from the Rubbertown area to the West End area. On the basis of the areas judged to be most affected by air pollution and the corresponding location of probable significant other sources of pollutants, coordinated meteorological and air sampling betworks were laid out. The location of most of the meteorological equipment (and air sampling equipment) is shown in Figure 2-1. A summary of meteorological measurements made is given in Table 2-10. The U. S. Weather Bureau Station at Standiford Field was designated as station 12.

In selecting sites for installation of equipment, some general criteria were used. Sites at which surface wind measuring equipment was installed (stations 1, 3, and 8) were selected to be relatively uninfluenced by nearby obstacles. The criterion adopted was that the distance from the installation to any obstacle must be at least ten times the obstacle height. Sites at which surface temperature and humidity were measured were required to be free of over-hanging trees, and uninfluenced by nearby features that might directly affect the ambient air temperature. This criterion was, in practice, already met by the more exacting criterion for exposure of wind instruments at those sites where both wind and temperature measurements were made (station 1, 3, and 8); the temperature criterion was used to select locations for stations 9, 10, and 13. Locations for rain gauges were required to be free of over-hanging trees and at a sufficient distance from obstacles to avoid local eddies. This criterion was met by the wind instrument criterion at the two locations where rain gauges were installed (stations 1 and 3).

Wind(surface). Beckman and Whitley Model K100A wind speed and direction recording systems were installed at stations 1, 3, and 8. This system was selected because it had the lowest threshold of all continuous recording instruments available. Wind speed and direction transmitters were mounted 55 feet above ground on light weight "pop-up" domestic TV towers. Each tower was located at the center of a triangular fenced enclosure. Recording instruments were housed in cabinets at ground level. Wind direction vanes were oriented using a sighting on the North Star. Factory calibrations of the systems were considered adequate.

Data tabulated from wind speed recorder charts were hourly average, maximum, minimum, and range. Data tabulated from wind direction charts were hourly average; persistence; fifth highest veering and backing directions; range; and damping.

Wind speed and direction data were also available from Standiford Field (station 12). Standard U. S. Weather Bureau equipment and procedures were being used. Sensing elements for wind equipment were located 71 feet above ground level on a pole on top of the airport terminal building.

An Instruments Corporation Anemograph Model R-339 wind speed and direction recording system existed at the E. I. du Pont de Nemours Company, in Rubbertown (designated station 7). The company operated the unit throughout the study and made resulting data available. Wind sensing elements were 96 feet above ground. Data were tabulated in a similar way to that for surface wind units operated by the study staff except that veering and backing directions could not be obtained because data were taken from recorder charts on a half-hourly basis.

Wind (524 feet above ground). A Bendix-Friez Aerovane wind speed and direction recording system was installed at the WHAS-TV tower in downtown Louisville (station 11). Wind sensing elements were mounted on the tower 524 feet above the ground, giving a measure of airflow relatively unaffected by roughness characteristics of the underlying surface. Recording instruments were at ground level. The wind direction vane was oriented using a sighting on the North Star. Factory calibration of the instrument was used. Data tabulation from recorder charts was the same as that for surface wind units operated by the study staff.

Temperature and humidity (surface). Standard Weather Bureau temperature and humidity measuring instruments and instrument shelters were used in this study. "Cotton Belt Region" shelters, each containing a maximum thermometer, a minimum thermometer, a wet and dry bulb psychrometer, a psychrometer fan assembly, and an Instruments Corporation hygrothermograph were used. The hygrothermographs utilized a human hair humidity element and a Bourdon tube temperature element. Mercury-in-glass thermometers were used for the wet and dry bulb thermometers and the maximum thermometers. Alcohol-in-glass thermometers with a contained glass indicator were used for the minimum thermeters. The thermometers were used as standards for adjusting the hygrothermograph traces and records.

Shelters and instruments were installed within within the triangular fenced areas at stations 1, 3, and 8. At stations 10 and 13, shelters were installed inside ten by ten foot square fenced areas, and at station 9, within the fenced area between two pump houses.

Data tabulated were hourly average temperature and relative humidity and daily maximum and minimum temperature and relative humidity.

The Weather Bureau Station at Standiford Field (station 12) provided similar measurements.

Precipitation. Instruments Corporation Universal Recording Rain Gauges were operated at stations 1 and 3. They were located within the triangular fenced areas at these stations. Factory calibrations were considered adequate. The hourly amount of rainfall was tabulated. Similar data were available from station 12 (Standiford Field).

Solar Radiation. A continuous record of the total incoming radiation (direct solar plus sky) was obtained by use of an Instruments Corporation pyrheliograph. It was operated at 43rd and Vermont Streets during the early part of the study and at station 1 during the latter part. The instruments' operation is based on differential bending due to different temperatures of two bi-metalic strips; one dull black and one polished metal. Data are interpreted in terms of gram calories per square centimeter per m minute (langleys) of radiation. Hourly totals were tabulated. Factory instrument calibration was used.

Vertical Temperature Gradient. The difference in temperature at points 6 and 55 feet above ground was measured and recorded at station 1 using a Beckman and Whitley Model 233-1 temperature gradient control unit. Sensing elements were mounted on brackets extending two feet from the tower installed at the station. Aspirated thermistor compensated thermocouples contained in radiation shields were used for temperature sensing elements. Temperature differences between the upper and lower sensing elements from minus 5 to plus 10 degrees C. were recorded. Recorder charts were examined for periods of interest (e.g. tracer runs), and with wind and hygrothermograph data, were used to establish the state of air flow.

Vertical temperature gradient was also measured at station 11 (WHAS-TV tower) using a Leeds and Northrup temperature difference measuring system. Temperature sensing elements were shielded asperated thermohm units and were installed at 60, 170, and 524 feet above ground on five foot beams hinged out from the tower. The recorder printed out instantaneous values of reference temperature from the lowest thermohm unit, difference between the lowest level and the middle level, and difference between the lowest and highest level, in rotation. About six minutes were required for the three recordings. Hourly averages for the three values recorded were tabulated. Factory calibration was considered adequate. The installation did not become operable until late in the study (August 1, 1957).

To supplement vertical temperature gradients made at the two fixed stations, about 45 runs were made to measure this parameter using a wire-sonde system (AN/UMQ-4). Wiresonde units, consisting of a radiation shielded thermistor unit ventilated by a battery operated blower, were carried aloft as high as 1000 feet above ground by a helium filled "Kytoon". A cable attached to the "Kytoon" controlled its elevation and served as a transmission line from the thermistor unit to indicating electrical meters on the ground. A clinometer was used to measure the elevation angle of the "Kytoon" and a counter on the cable reel indicated the length of cable out. From this information, the elevation of the "Kytoon" above ground was calculated. Reduced data for each run were elevation above ground and temperature. More than half the runs were made during a period of feeble air movement in mid-October 1956.

U. S. Weather Bureau airport station. Hourly observations made at Standiford Field (station 12) included temperature, humidity, wind, visability, obstructions to vision, sky conditions, and barometric pressure. Hourly rainfall amounts, daily temperature extremes, precipitation totals, sunshine, average wind speed, and sky cover, were noted. Other data were computed or derived.

The hourly observations recorded at Standiford Field represented instantaneous data, except for wind speed, which was a one-minute average. These data thus differed from the data from other sites, which were hourly average values from recording instruments. There was the possibility of subjective bias in the data for those elements requiring observer judgement. The elements of greatest use for this study, wind direction and wind speed, both required some judgement, because they were obtained from direct-reading, rather than recording devices.

Weather Forecasts

In July 1956, arrangements were made with the Weather Bureau Airport Station, to furnish the air pollution study staff with daily weather services for use in field operations. The daily weather services included: 1. Forty-eight hour general weather forecast and a succeeding 24 hour general outlook. 2. Five day general weather outlook (on Monday, Wednesday and Friday). 3. Description of synoptic situation with emphasis on pressure systems,fronts, and other meteorological phenomenon likely to affect Louisville during the forecast period. 4. Twenty-four hour forecast for surface and 5000 foot winds and succeeding 24 hour general outlook.

Briefing of personnel was performed by the study meteorologist during periods of intensive air sampling or during weather periods which appeared likely to cause significant episodes of pollution in West End Louisville.

Feeble air movement episodes. Attempts were made to anticipate the occurrence of stagnant weather periods of two to four days duration with special emphasis upon the fall season of 1956. The Weather Bureau Airport Station included an outlook on occurrence of this type weather regime in the daily weather forecast. One such period occurred from October 14 through 17, 1956. On advice from the Cincinnati and Louisville forecasting offices, a continuous series of wiresonde observations were conducted beginning at 2100 CST, October 15, 1956, and ending at 1530 CST, October 17, 1956 at E. Leland Taylor Park in Louisville, Several special gaseous pollution samples were collected during this period.

Classification of Air Sampling Periods According to Direction of Air Movement

A method of classifying sampling periods was devised to provide three general groupings of high volume particulate samples collected at six sampling locations. These three groups were: (1) flow from Rubbertown to the sampling location (a Rubbertown wind); (2) flow not from Rubbertown to the sampling station (a non-Rubbertown wind); and (3) flow of variable direction that would include both grouping (1) and (2) during the sampling perriods (a mixed wind).

The azimuth sector from each station to the limits of the Rubbertown area were determined from maps. The several wind directions out of the 16 compass points that included this sector, together with the two directions immediately adjacent to the sector borders were taken to represent the directions of flow from Rubbertown to the sampling site. All other directions of flow were taken to represent flow not from Rubbertown. The sector and wind directions used are shown in Table 2-11.

The method used for classification of a given sampling period for a sampling station was to examine reported wind directions at a nearby reference wind measuring station for a 10-hour interval extending from one hour before the start of an eight-hour sampling period to one hour after the end of the sampling period. If the reported wind directions for all ten hours were from Rubbertown directions, the sampling period was provisionally classified as a Rubbertown case; if all ten hours were from non-Rubbertown directions, the sampling period was provisionally classified as a non-Rubbertown case. A sampling period including hours of both Rubbertown and non-Rubbertown directions, could be definitely classified as a mixed case. The final determination of the Rubbertown and non-Rubbertown cases was made by examining reported wind directions at other wind stations. If these stations showed wind directions approximately the same as those reported for the reference wind station, generally within two compass points, the provisional classification was considered verified. If wind directions at the other stations differed appreciably from those at the reference station, the classification was changed to mixed.

These groupings are determined by the direction of air flow only and do not, per se, provide a selection according to other meteorological criteria. However, since all meteorological influences are interrelated, these selections do segregate the sampling periods to some extent according to other criteria. A large proportion of the sampling periods that are of great interest, because of light and variable flow, often with winds from opposing directions at various locations, would be included in the mixed grouping, as would be cases of strong shifting winds. A Rubbertown case at any of the sampling stations in the west end (nos. 1, 4, 5, and 6) meant a southerly flow, bringing warm air over the region.

AIR QUALITY STUDIES

The air sampling program was designed to give maximum information relative to study objectives within available resources. A complete record would have required continuous measurement of concentrations of each pollutant at a multitude of points. Since such a program was not economically feasible, a program incorporating as many desirable features as possible was attempted. Studies conducted are described briefly in this section. Further details of some of the methods are given in Appendix D.

Air Sampling Network

Six permanent air sampling stations were established (Figure 2-1); stations one through six). Since the contribution of pollution arising in Rubbertown to pollution levels in the West End of Louisville was of special interest, the network was designed with Rubbertown as its primary reference point. Stations were located in such a way that changes in air pollutant concentrations as air passed over Rubbertown could be determined as well as pollutant concentrations at points across wind from Rubbertown. Four of the six permanent air sampling stations were located in West End Louisville to provide as much information as feasible about air quality in this area of special interest. Continuous sampling at the six stations by use of high volume air filters and AISI strip filter paper samplers provided assurance that at least these data would be available should an air pollution episode occur. The continuous data were also of greatest use in studying effect of meteorological parameters on air quality.

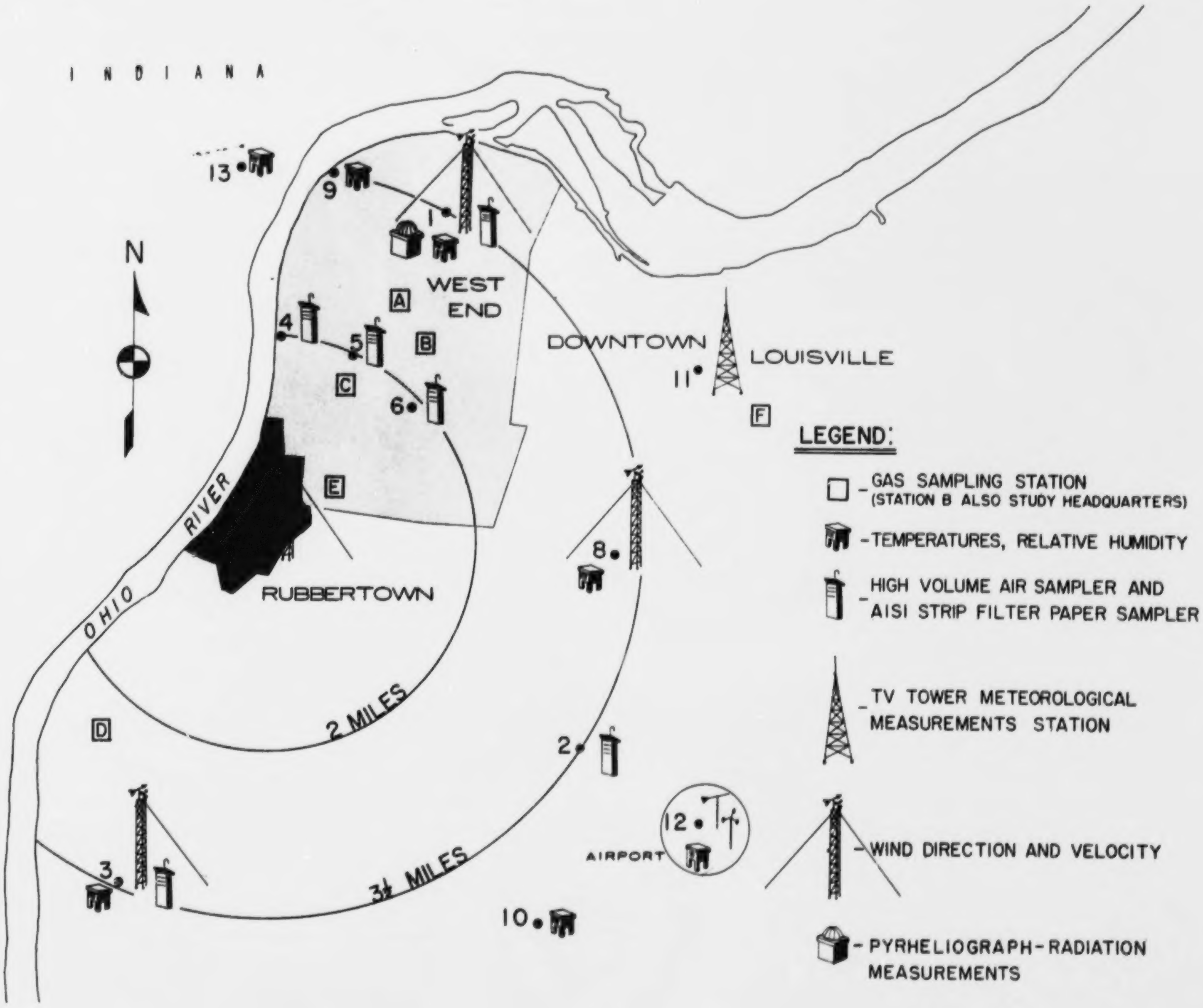
A network of stations for gas sampling was also established (Figure 2-1; stations A through F). Various gases were measured at these stations for varying periods of time. Sulfur dioxide was measured continuously at two stations (A and B) throughout the study.

Samples of gaseous and particulate pollutants were collected at other locations in the area from time to time.

The high volume and AISI samplers were located at air sampling network stations numbered 1 through 6 (Figure 2-1). Samplers were housed in shelters constructed of plyboard (Figures 2-2 and 2-3). Free air passage to the high volume samplers was provided by louvers near the top on each side of the shelter and by screened ports at the shelter bottom.

Collection of Suspended Particulate Matter By High Volume Sampler

A high volume air sampler of the type used in the Public Health Service National Air Sampling Network [24] were operated continuously at stations one through six. The sampler consists of a vacuum cleaner-type motor in a housing attached to a filter paper holder. Air volume passing through an eight by ten inch filter varies from approximately 70 cfm for a clean filter to 30 cfm for a filter loaded with approximately one milligram of particulate per square centimeter of filter surface.


INDIANA
13
9
1
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DOWNTOWN
LOUISVILLE
11
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E
OHIO RIVER
RUBBERTOWN
8
2 MILES
D
2
12
AIRPORT
3
3½ MILES
10
LEGEND:
GAS SAMPLING STATION (STATION B ALSO STUDY HEADQUARTERS)
TEMPERATURES, RELATIVE HUMIDITY
HIGH VOLUME AIR SAMPLER AND AISI STRIP FILTER PAPER SAMPLER
TV TOWER METEOROLOGICAL MEASUREMENTS STATION
WIND DIRECTION AND VELOCITY
PYRHELIOGRAPH-RADIATION MEASUREMENTS

Figure 2-1. BASIC AIR SAMPLING AND METEOROLOGICAL NETWORK

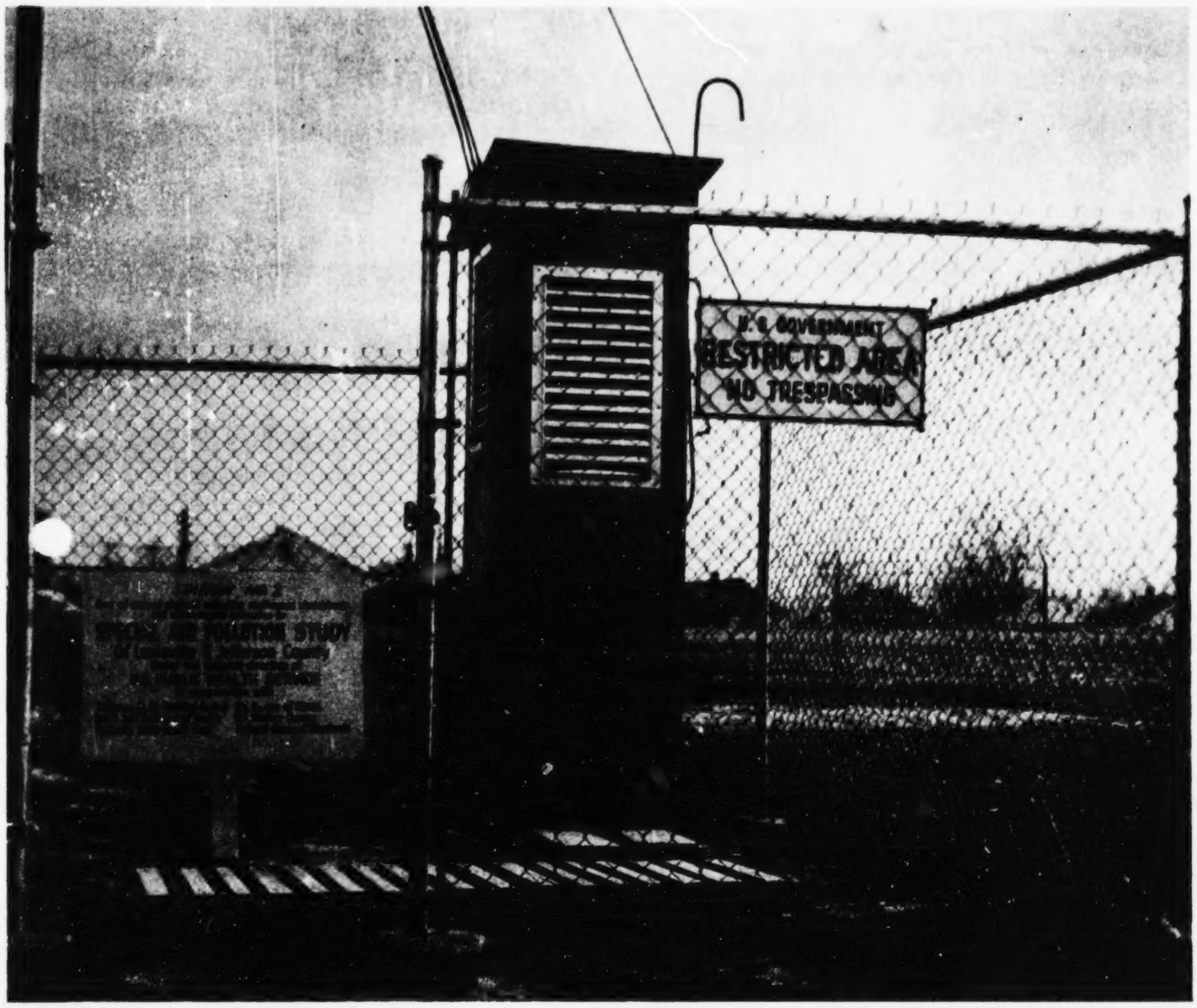


Figure 2-2. AIR QUALITY MEASURING STATION

High volume air samplers were mounted in the shelters with the filter paper in a horizontal position, facing upward, minimizing bias due to wind direction. Two high volume samplers were provided at each station and were operated alternately. Sampling periods were 2400 to 0800; 0800 to 1600; and 1600 to 2400 CST. Automatic timers in each shelter activated and deactivated the samplers.

Preventive maintenance on a bi-monthly schedule, at the time of recalibration, helped to secure accuracy of sampling results and long motor life for high volume samplers. The median life of motors was approximately 2500 hours.

At the start of the Louisville study, and until September 14, 1956, high volume particulate samples were collected on Mine Safety Appliance Company glass fiber filter paper No. 1106-B (flash fired). This filter medium was selected because of its good collection efficiency, ease in obtaining accurate weighings, and its adaptability to determinations of organic matter collected. However, analyses indicated that the glass fiber paper contained chlorides, sulphates, and calcium in

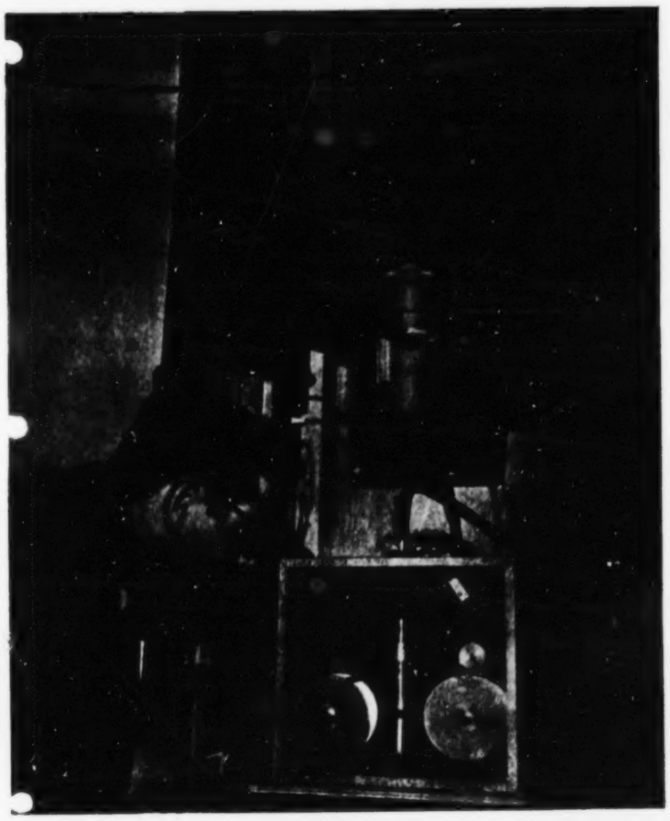


Figure 2-3. CLOSE UP VIEW OF INTERIOR OF AIR SAMPLING STATION

appreciable amounts, that the amounts varied, and that this variation in many cases was greater than the quantity collected in a sample.

	Micrograms per 8 by 10 in. sheet	
	MSA glass fiber 1106B	Whatman 41-H
Chloride	500-25,000	less than 200
Sulfate	100- 3,000	less than 200
Calcium	1500-12,000	100 - 200

Therefore, in order to determine accurately chloride, sulphate, and calcium concentrations, it was necessary to change to Whatman 41-H cellulose paper which contained only small and constant amounts of chlorides, sulphates, and calcium. This filter medium was used from September 15, 1956 to the end of the study.

Total weight of suspended particulates. Different routines were used for analyzing samples from glass fiber paper and cellulose fiber paper. Glass fiber paper was weighed before and after sampling, the net change in weight being the total particulate collected. Cellulose paper, due to change in weight with humidity, was weighed after being held in a controlled atmosphere for 24 to 48 hours. A reference sheet of unexposed paper for each set of 25 filters was subjected to the same controlled atmosphere, and provided data to make small filter weight variation corrections. Total particulate concentration in $\mu g/m^3$ was determined by dividing the sample weight by the air volume. The air volume was the product of the sampling time multiplied by the average of the starting and stopping air volume rates. Total weight of particulate matter collected was determined for all high volume air samples.

Selection of samples for detailed analysis. Since laboratory capacity was insufficient to analyze all fractions of all suspended particulate samples, a selection of samples for detailed analysis was made. Three methods of selection were used: first, samples to represent low, medium, and high total particulate concentrations, chosen from the distribution of concentrations; second, a selection based on the direction of air flow to provide a comparison of quality of air coming from Rubbertown with quality from other areas (see method of classification under title "Classification of Sampling Periods According To Direction of Air Movement" in section on Meteorological Studies in this chapter); and third, a reserve to permit analyses of samples selected according to other special criteria. An example of use of the first method was selection of 36 samples from the 90 available from station 1 for April 1956. From each of the three daily sampling periods, the four lowest, four medium and four highest values of total particulate concentration were selected. This resulted in a group of samples in which the three daily sampling periods were equally represented, and the three concentration ranges (low, medium, and high) were equally represented.

Benzene soluble matter. After weight determination for total particulate, sample filters were cut in half. One-half of the sample was used for determining benezene soluble material (Figure 2-4), and the other half was held for further analysis. Benzene soluble matter was removed from filters using a soxhlet extractor. The extract was filtered, evaporated down at 60 degrees C. and weighed. Concentration of organic particulate matter in

Figure 2-4. EXTRACTING ORGANIC FRACTION FROM HIGH VOLUME FILTER SAMPLE

the air sampled was calculated as $\mu g/m^3$. (See details in Appendix D)

Chloride, sulfate, and nitrate analyses. The half of the particulate sample from which benzene soluble material had been extracted was used in these procedures, for this sample gave more complete recovery of water soluble materials than one which had no preliminary benzene treatment. Chlorides, sulfates, and nitrates were extracted from the filter with boiling water. After filtering, iron and other metals which would interfere with the nitrate determination were removed from the filtrate by action of an ion exchange resin. (See Appendix D). Chloride was determined by titrating against a standard solution of mercuric nitrate at a pH of 3.1, forming slightly dissociated mercuric chloride. Excess mercuric ions produce a violet color with the diphenylcarbazone indicator used.[25] Bromphenol blue is added to the indicator to facilitate pH adjustment. Sulfate concentration was determined using the method employed in the National Air Sampling Network.[24] Sulfate ions in the water extract combine with barium ions in acid solution, producing a precipitate. Light transmitted through the turbid solution was measured with a spectrophotometer and compared with a calibration curve.

Nitrates were determined using a modification of the Griess-Ilosvay method developed by Charles Gelman,[26] one of the study chemists. The method is based on reduction of nitrates in the water extract to nitrates, formation of a diazonium derivative of benzenesulphonilamide, and then coupling to form a diazo dye. Any nitrate originally in the sample would increase final results. Analysis of the Louisville samples indicated that the nitrate contribution was only one or two percent of the total nitrate concentration, so this small contribution was ignored. Results were expressed as $\mu g/m^3$ of air.

Calcium analysis. Since the source inventory indicated significant emission of calcium bearing particulate matter from one Rubbertown source, calcium could be used to depict the transport of pollutants emanating from that source. As a built-in tracer, calcium content of particulate matter was valuable in studying the effect of wind direction and other meteorological variables on resultant ground level concentrations in western Louisville. A flame photometric method was used to provide rapid and precise calcium concentration results (Figure 2-5). Parts of the Whatman 41-H filters from high volume samplers were extracted in ten percent nitric acid, diluted with

Figure 2-5. CALCIUM ANALYSIS OF SUSPENDED PARTICULATE MATTER BY FLAME PHOTOMETRY

distilled water to two percent acid, filtered, aspirated into an oxyacetylene flame, and the emission intensity determined at 422 and 554 mμ wave lengths. Further details are given in Appendix D.

Automatic Strip Filter Paper Sampling

Sampling with AISI (American Iron and Steel Institute) strip filter paper samplers made possible a more detailed picture of diurnal variation in concentration of suspended particulate matter since 6 or 12 samples were taken per day at a station as compared with three high volume samples. Samplers were located on the bottom shelf of air sampling shelters (Figure 2-3). Air was drawn into the sampler through an inverted one-half inch diameter copper tube at a point one foot above the sampling shelter. Air velocity into the inverted intake insured that only suspended particulates smaller than approximately five microns diameter (computed using Stokes' law) would be drawn in. Thus, sample characteristics were, in large degree, influenced by particles of sizes which markedly influence visibility.

Samples were collected on a one inch circular area of Whatman No. 4 filter paper tape at an air flow rate of about 0.25 cfm. At the end of a sample cycle the tape was automatically advanced to a clean portion. A light transmission type spot evaluator was used to measure sample optical density. Results were tabulated in terms of Coh units. 27/

Dustfall Measurements

Dustfall was measured by the Jefferson County Air Pollution Control District, using a network of open jar dustfall stations sampling on a monthly basis. Results were reported as tons per square mile per month of total water soluble and insoluble dustfall.

To determine the type and source of the settled dust greased slides were set out at 71 locations for three-day periods, a period sufficient to allow collection of an adequate amount of dust but without frequent interference from rain. Samples were collected at the start of the program on one inch by three inch glass slides, coated with vaseline. The vaseline interferred with subsequent X-ray diffraction examinations, however, so the coating was changed to Shillaber's oil, which proved satisfactory. In order to secure enough settled dust for x-ray diffraction examination using a three-day sampling period, it was necessary to increase the size of slides to 10 inches by 12 inches. The large slides were prepared by placing five drops of Shillaber's oil on a slide, spreading it with a windshield wiper blade, and placing the oiled faces of two slides together to prevent contamination before sampling. Exposed slides were transported in closed boxes. Some samples were observed under a binocular stereoscopic microscope at 400 magnifications for preliminary identification of collected dust. The particulates on each slide were scraped into a small pile, transferred to a plastic vial, and forwarded to the National Bureau of Standards for x-ray diffraction examination.

Sampling Methods for Gaseous Air Pollutants

Measurements of gaseous air pollutants were made to determine levels of several gases which occur and to relate these levels to odor and irritant thresholds. Certain gases were measured to indicate the contributions of particular sources of pollution. Sulfur dioxide, nitrogen dioxide, and aldehydes were expected from fuel burning. Acetylene, chloride, and phenol were expected to indicate certain Rubbertown industrial emissions. Total oxidants and ozone were expected to indicate air pollutants which might be produced in the atmosphere by interaction of constituents such as hydrocarbons and nitrogen dioxide in the presence of sunlight.

Samples of gaseous air pollutants were collected using routinely operated equipment and by collection of special samples as circumstances indicated. Routine samples for several individual pollutants were collected at several locations for a number of weeks in order to determine general air quality. Special samples were collected as instantaneous grab samples or as short duration freeze-out samples during air pollution fumigations, and each sample was analyzed for many constituents.

Sulfur dioxide was measured continuously with Thomas Autometers at 37th & Broadway (station B) and at study headquarters at 4000 Michigan Drive (station A). Hourly means and maxima were tabulated.

Twenty-four one-hour samples per day were taken for determination of chloride using the

Wilson Automatic Impinger. Samples were collected five days per week over a two month period at two stations. The sampler operated by metering thirty ml of distilled water into a standard Greenburg-Smith impinger, drawing air through the impinger at ten lpm for one hour, draining the impinger contents into a tube held in a rotating rack, advancing the rack to the next empty tube, and repeating the cycle. The samplers were placed in shelters used in the continuous air sampling network with air sampling tubes extending outside.

Aldehyde samples were collected sequentially in midget fritted bubblers attached to an automatic sampler developed by the Kettering Laboratory of the University of Cincinnati. The sampler consisted of a timer control mechanism and rotating manifold, contained in a box. Bubblers were attached to the outside of the box. Hoses were connected from the suction side of the bubblers to 12 inlet ports located radially about the manifold. A center arm was rotated from one inlet port to the next by a motor activated at the end of each time cycle. Air flow through the manifold was measured by a rotameter attached to the manifold suction line. Air flow was adjusted to a constant rate with a needle valve attached to the flowmeter.

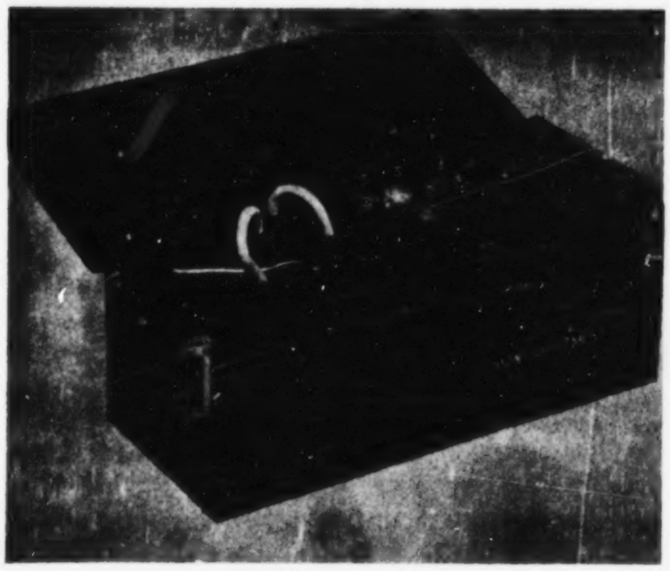


Figure 2-6. GELMAN SEQUENTIAL SAMPLER

The Gelman Sequential Sampler (Figure 2-6) was used for sampling aldehydes and phenols. The 12 midget bubblers used were housed in a steel carrying case which also contained a pump and timing mechanism. The carrying case provided protection during outdoor sampling. The exhaust port on each bubbler was connected to a manifold exhausted by a small bellows-driven pump contained in the sampler. Stainless steel solenoid valves were automatically closed by the timer at the end of a sampling cycle and the valve to the next bubbler was opened. Air flow rate was measured with a rotameter attached to the outside of the sampling case.

Many routine gas samples were collected in a multi-component sampler developed by the study staff. The sampler was designed to collect samples for determination of as many as seven gases simultaneously. It consisted of a plywood box, block drilled to hold midget impingers or bubblers, seven impingers or bubblers surmounted (through the top of the box) by individual membrane filter holders, seven adjustable flow rotameters attached to the back of the box, and a common exhaust manifold. When sampling, air was drawn through the membrane filters, into the impingers or bubblers, metered through individual rotameters, passed into the common manifold, and exhausted from the manifold by a pump or by vacuum from an automobile windshield wiper line.

A continuous freeze-out sampling apparatus was devised for taking special gas samples. The apparatus consisted of two freeze-out traps, a one liter Dewar flask, a two liter Dewar flask, a float level controller, and a rotameter. The apparatus also had a 2.5 hp pump and a 25 liter Dewar oxygen flask connected by a supply line to the two liter Dewar. Air, metered at 1.5 to 2 lpm, was drawn through the first freeze-out trap, the second freeze-out trap, and the rotameter, and was exhausted through the pump. The first freeze-out trap, maintained at 32 degrees F. by emersing the bottom of a U-tube trap in cracked ice in the one liter Dewar, was used to condense moisture before collecting gases in the second trap. The first and second traps were joined by a ball and socket joint. Gases were condensed and collected in the second trap, maintained at about minus 185 degrees C. by emersing the bottom of a U-tube in liquid oxygen contained in a two liter Dewar.

The liquid oxygen level in the two liter Dewar was maintained automatically by a float switch. When the float dropped to a predetermined level, a switch activated a pump that pressurized the oxygen storage Dewar, forcing liquid oxygen into the freeze-out Dewar until the float reached a predetermined level when a second switch was activated, turning the pump off. This continuous freeze-out sampling apparatus was used satisfactorily when high pollutant concentrations persisted for prolonged periods. Grab type freeze-out sampling apparatus was used for determining peak concentrations during short duration fumigations. Samples were analyzed by use of a mass spectrometer by the National Bureau of Standards.

Instantaneous grab samples of gaseous pollutants were taken during air pollution fumigations in order to identify the pollutants which caused the fumigation and to determine their concentration. Increasingly large grab samples were taken until a satisfactory volume, sufficient for analysis with a mass spectrometer, was obtained. Two liter evacuated flasks were used first, but proved too small. Thirty-three liter U. S. Air Force oxygen tanks were next used, and these provided a bare minimum volume for analysis. Since small amounts of certain contaminants were difficult to determine with the smaller samples, a 1440 liter stainless steel tank (Figure 2-7) was used. The tank was three feet in diameter and approximately seven feet long. It was constructed of one-eighth inch stainless steel, braced internally at three points with stainless steel plate in order to withstand the pressure on the tank when it was evacuated. Stainless steel welds were made at all joints. Stainless steel nipples were welded to each end and brass needle valves were fitted. After evacuating the tank several times, drierite and activated carbon were placed in a tube ahead of the tank inlet, and the tank was purged for several hours. These cleansing precautions were taken when the tank was first used and after each sample was collected. The tank was mounted in a panel truck. When a fumigation was reported, the evacuated tank was sent to the scene and the valve opened to collect the sample. The sample was returned to the laboratory for further processing.

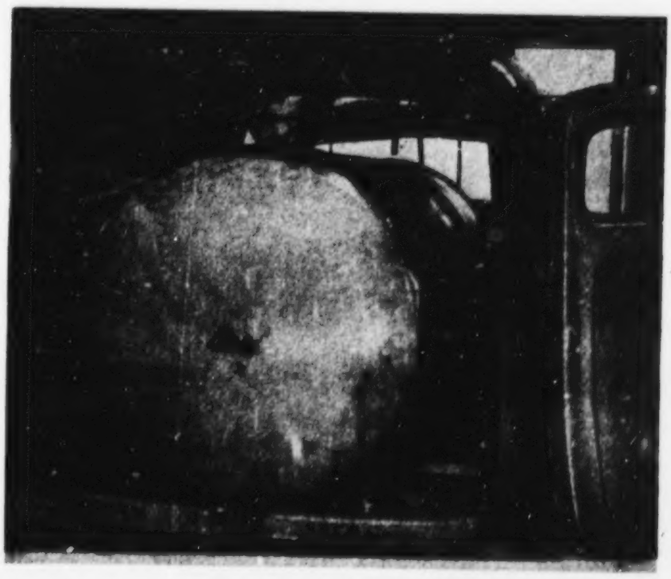


Figure 2-7. 1440-LITER STAINLESS STEEL TANK FOR GRAB SAMPLING

Analysis of Gas Samples

Acetylene. The method used for determination of acetylene was developed for the study by the National Bureau of Standards Gas Chemistry Section. 28/ The method consists of collecting acetylene on silica gel at dry ice temperature, reacting the acetylene with an indicator solution to develop a characteristic pink color, and determining the amount of reacted acetylene by comparing the color with prepared standards.

Aldehydes. The Goldman-Yagoda Iodometric method 29/ was used to measure low molecular weight aldehyde concentrations in the air. The method depends on forming an aldehyde-bisulfite addition product when the air being sampled is aspirated through one percent sodium bisulfite solution. After sampling, the excess bisulfite is destroyed with iodine and the aldehyde-bisulfite complex is decomposed with buffer solution. The bisulfite released is titrated against 0.01 normal iodine solution, using a semi-micro burette. The procedure is reported to be efficient for low molecular weight aldehydes with little sensitivity for higher molecular weight aldehydes.

Chloride (as HC1). Gaseous chloride concentrations were determined using the same analytical procedure as used for chlorides except that a more dilute mercuric nitrate solution (chloride equivalent equal to 100 ug/ml of solution) was used. Prefilters were used to exclude particulates from the gas samples.

Nitrogen dioxide. The method described by Saltzman[30] was used to determine atmospheric nitrogen dioxide concentrations. This method, based on the reaction of nitrogen dioxide with Saltzman's reagent, produces a stable color which can be accurately evaluated for concentrations in air as low as a few ppb in samples taken over ten minute periods at a flow of 0.4 lpm. The reagent has been demonstrated to be specific and to absorb nitrogen dioxide efficiently in a midget fritted bubbler.

Total oxidant. This method,[31] based on the oxidation of phenolphthalin ($C_{20}H_{16}O_4$) to phenolphthalein ($C_{20}H_{14}O_4$) by oxidants in the air, provides a sensitive method for detecting small quantities (as little as one ppm) in air.

Ozone. The Smith-Diamond method[32] was used for determining ozone concentrations. In this method ozone is absorbed from air by passing it through an alkaline potassium iodide solution. Iodine, released after acidification, is determined spectrophotometrically by measuring absorption of the triiodide ion at 352 mμ wave length.

Phenol. A sensitive method[33] was used to measure concentrations as low as two ppb of phenol in air. Concentrations were determined by photometrically measuring the color intensity produced after oxidizing the phenol collected in the absorbing solution in the presence of p-aminodimethylanaline sulfate.

Sulfur dioxide. The West-Gaeke method[34] was used to determine sulfur dioxide in air in addition to the Thomas Autometer. Air was bubbled through 0.1 molar sodium tetrachloromercurate (II) solution. Sulfur dioxide reacts to form stable, non-volatile disulfitomercurate. A red-violet color is produced when a p-rosaniline hydrochloride and hydrochloric acid mixture and formaldehyde are added to the sampling solution. Optical density is measured at 560 mμ to determine sulfur dioxide concentration.

Processing of grab samples. After a grab sample was collected in the stainless steel tank, two transfers of the sample were required. The first was accomplished using a modified Shepherd cold trap connected to the downstream end of the stainless steel tank. A mercury manometer was connected to the upstream end of the tank to measure internal pressure as sample transfer proceeded. The Shepherd trap was immersed in a liquid oxygen bath and the sample was drawn through the cold trap at a rate of 1.5 to 2 lpm with a vacuum pump until the necessary volume of gas (approximately 400 liters) was transferred. The volume transferred was calculated from the pressure drop in the tank, tank volume, and atmospheric pressure at time of transfer.

The second transfer of the sample was from the freeze-out trap to a small (500 ml) transfer bottle suitable for shipping. An evacuated system containing the transfer bottle and a pressure indicating manometer was connected to the freeze-out trap while the trap was still immersed in liquid oxygen. The liquid oxygen bath was moved from the freeze-out trap and placed around the transfer bottle. As the freeze-out trap warmed to room temperature, the pollutants volatilized, passed over to the transfer bottle, and were recondensed. All-glass equipment was used. After the transfer, the bottle was packed in dry ice and shipped to the National Bureau of Standards in Washington D.C. for mass spectrometric analysis.

Pollutants collected in the 33 liter stainless steel flasks were also condensed in cold traps, but the first transfer procedure varied somewhat from that used for the 1440 liter samples. The Shepherd cold trap was connected to one end of the 33 liter flask. Room air was passed through activated carbon, drierite, and soda lime, and into the other end of the flask. The vacuum pump downstream from the freeze-out trap drew two lpm of purified air through the trap until a volume of air equal to seven times the 33 liter flask volume had passed through the trap. The sample was then removed to a small transfer bottle as previously described and shipped to the National Bureau of Standards for mass spectrometric analysis.

Bacteriological Study

A study of air-borne bacteria was conducted on request of the Louisville-Jefferson County Board of Health. The purpose of the study was to develop preliminary knowledge and understanding of air-borne bacteria in the outdoor air with specific regard to the number of bacteria present and changes in number present with season of the year. Since very limited data concerning bacteria in outdoor air are available, it was difficult to determine the significance of data collected.

The number of air-borne bacteria in the air over western Louisville was measured by investigators from the Communicable Disease Center of the U. S. Public Health Service. Samples were taken on a seasonal basis during four periods. The periods, each of five days duration, were November 12-16, 1956; February 11-15, 1957; May 13-17, 1957; and August 5-9, 1957. Series of air samples were collected between the hours 0800-1100 in the morning and 1300-1600 in the afternoon. Individual samples were of approximately 20 minutes duration. Samples were collected at a station 1 (Figure 2-1) in E. Leland Taylor Park.

Air-borne bacteria were collected using three types of sampling devices operated simultaneously. A tangential jet sampler was employed as a liquid impinger; a Casella slit sampler (Figure 2-8) as a solid-agar impinger; and a standard petri dish as a settling plate. Air flow through the volumetric samplers was obtained using a vacuum pump. A stainless steel critical orifice in the vacuum line was utilized to maintain an air flow of 1.04 cfm through the slit sampler. For the tangential jet sampler air flows ranging from 0.66 to 1.39 cfm were metered, using an orifice at the tapered end of the inlet tube. Differential pressures across the critical orifice and tangential jet sampler were measured with mercury manometers. All air samples were collected five feet above ground level with the three types of sampling devices placed approximately three feet apart on a line perpendicular to the prevailing wind direction. The Settling plate was exposed during the same interval that volumetric samplers were in operation. Collecting media for the settling plate and slit sampler consisted of a tryptose-agar base containing 5 percent normal, sterile defibrinated sheep blood. The liquid collecting medium utilized in tangential jet samplers was 0.25 percent Difco Peptone in water.

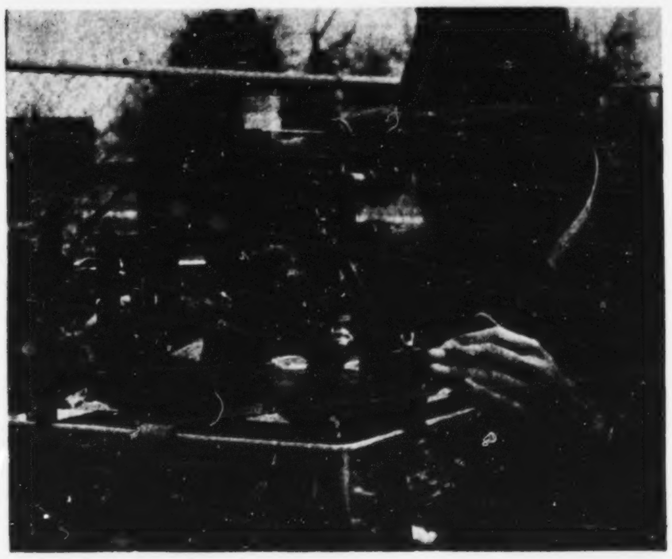


Figure 2-8. CASELLA SLIT SAMPLER FOR COLLECTING BACTERIA

Immediately following collection of each sample, exposed agar plates were covered and placed in petri dish holding cylinders. The liquid collecting medium from the tangential jet sampler was streaked on blood agar plates at the sampling site immediately following collection; a volume of 1.5 ml was streaked on five agar plates in aliquots of 0.3 ml. At the completion of sampling in the morning and afternoon, exposed and streaked blood agar plates were placed in an incubator at 37 degrees C. After 48 hours of incubation bacterial colonies on the agar surfaces were counted with the aid of a modified Quebec colony counter. The number of bacteria collected was determined from the total colony count of each sample. Each colony was assumed to represent a single bacterium.

ODOR THRESHOLD DETERMINATIONS

The source study and the gaseous air quality study indicated the presence of several pollutants in western Louisville which were thought to cause public complaints of odor pollution but for which human odor detection thresholds were unknown. Thresholds were determined for five of these pollutants. Thresholds for others were obtained from the literature. These thresholds were compared with measured atmospheric concentrations to determine frequency and intensity of pollution by odorous materials.

Odor threshold concentrations were determined using 17 panelists and an odor evaluation apparatus [35/] developed for the Louisville Study (Figure 2-9). Two air streams, both precleaned by carbon filters, enter the apparatus. The pollutant diffuses at a known rate from a constant temperature diffusion flask into one air stream and is then diluted with precleaned ambient air and passed into a face mask worn by a panelist. The odorant concentration is

Figure 2-9. DETERMINING ODOR THRESHOLD

gradually increased until the panelist detects the odor, at which time he raises his hand. Thresholds were determined for each panelist at two different times separated by an intervening period of several days.

HUMAN RESPONSE TO AIR POLLUTION

A study of human response to air pollution was conducted to provide a daily record of subjective observations of odor; eye, nose, or throat irritation; or visible dustiness, and to provide a mechanism for informing study headquarters immediately of existence of severe pollution episodes as determined by subjective observation.

A trained Observer Corps was organized to secure information relative to air pollution conditions in 31 arbitrarily designated areas in western Louisville. The group was composed of 25 mailmen; five panels of firemen; 45 high school science students and other residents of the 31 areas; two staff members of the air pollution study; six public health sanitarians; and several Jefferson County Air Pollution Control District inspectors.

Odor discrimination tests were conducted to assure that participants had normal olfactory acuity. In addition, members of the group were instructed in the recognition of odors and were supplied with odor reference kits made up of 14 vials containing the principal odorous materials expected in western Louisville.

At the beginning of the project on November 1, 1956, observers were asked to record their observations each day on a report form and to send this to study headquarters at the end of each month. Examination of these forms indicated that many of them were not being filled out daily, but at much more infrequent periods when it would be difficult for observers to recall observations of pollution of several days past. To overcome this deficiency and to provide more current data, daily reporting and mailing of records was adopted beginning February 15, 1957 and continued until the end of the study on June 1, 1957. Reports from the various observers indicated that in some instances an observer completed a report only when pollution was evident, while others reported daily.

METAL DETERIORATION STUDY

Some West End citizens expressed the opinion that screens and other metal objects deteriorated more rapidly in western Louisville, than in other areas, due to air pollution. To evaluate this factor, the loss in strength was measured for calibrated steel springs exposed inside and outside of each air sampling shelter (stations 1 through 6, Figure 2-1).

The coil springs used (Figures 2-10 and 2-11) to indicate corrosion rate consisted of approximately 50 turns, formed on an automatic spring-winding machine. All were fabricated from the same roll of unplated nonnormalized carbon steel wire. After forming, springs were stored in dry air-tight containers. Prior to use they were thoroughly degreased by washing in a mixture of one-half toluene and one-half alcohol. Moisture repellent grease was applied to the hook at each end and the mountings of the test fixture to minimize corrosion of the contact points.

Spring tension was measured at intervals from February 1 to October 1, 1957 using a tensometer which was attached to one hook of the spring and pulled steadily until the spring was just disengaged from retaining arm of the test fixture, at which time the scale was read (Figure 2-10).

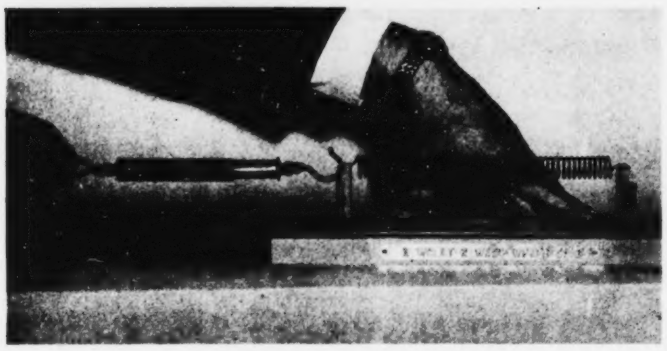


Figure 2-10. MEASURING SPRING TENSION

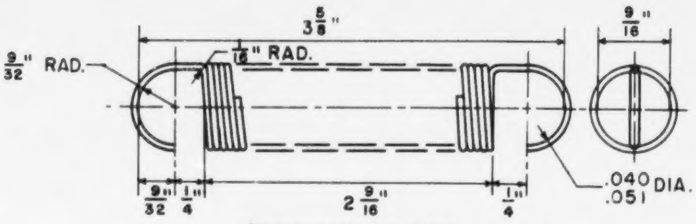


Figure 2-11. DIMENSIONS OF SPRING FOR CORROSION TESTS

DATA PROCESSING

Thousands of pieces of data resulted from the study. Approximately 10,000 high volume air samples were taken, and the total particulate concentration for each of these was determined. Selected samples were analyzed for such fractions as organic, calcium, chloride, nitrate, and sulfate. Data from AISI samplers, sulfur dioxide samplers, and other sampling equipment added additional information. Modern data handling methods, including the use of punched cards and electronic computers, were used to organize, classify, and process data. Further details on the handling and use of particular sets of data will be found in Chapter 3 with the preservations of sampling results, and in the Appendix.

CHAPTER 3

RESULTS OF STUDIES

Study objectives are given briefly in Chapter 1 and in more detail in Appendix A. The studies undertaken are outlined in Chapter 2 along with methods used. Further details of certain methods are given in Appendices B through D. Results of these studies are presented briefly in this chapter. It was necessary to summarize much of the data and to omit some in order to keep the size of this report within reasonable limits. A summary of findings for each section of greater length will be found at the end of the section.

POLLUTION SOURCE STUDY

Emission of pollutants to the atmosphere from sources in western Louisville for the year 1956 are described in this section. The methods used in determining emissions are described in a previous section (Study Activities and Methods - Source Studies). Details concerning methods and bases for calculation and estimation are given in Appendix B. Notations on the tables which follow indicate how particular values were derived.

Emissions were computed on an annual basis. Industrial and transportation emissions have moderate seasonal variation, the former being greater in winter months and the latter greater in summer months. However, these emission rates may be considered generally typical for any time of the year. Emissions from domestic and commercial sources, on the other hand, occur largely during winter months when space heating units are in use. Therefore, the relative contribution to total emissions attributable to these sources will be correspondingly greater in the winter and lesser in the summer.

The data for gaseous emissions do not include nitrogen, hydrogen, oxygen, carbon monoxide, carbon dioxide, argon, or water vapor. Some of these materials, and others may be of concern as pollutants but they have not been tabulated in this study. It should be understood that the lists of materials given as emissions from various sources do not necessarily include a listing of all materials emitted but do, with the exceptions stated above, include materials of major interest.

Particulate emissions are divided into coarse and fine size ranges at the 1μ diameter size. This size was chosen as a compromise between the size usually considered to have the greatest light scattering power (0.2-0.3μ) and the size below which toxicological effects from particles are most liable to occur (2-3μ). Such a division groups most of the tars, resins, and carbon particles in combustion effluents in the smaller size range. Ideally, perhaps three size categories should have been used, e.g., less than 0.5μ: 0.5-5.0μ: and greater than 5.0μ, in order to classify the particulates more satisfactorily in terms of both physical behavior and possible effects. Such a division was not possible because of lack of sufficient particle size information on effluents. Fine aerosol particles (less than 1μ) are responsible for most of the reduction in visibility and soiling of textiles, and are implicated as being associated with some adverse effects on health. Coarse particles (greater than 1μ in diameter) represent the "dust fall" portion of particulate pollution. Large particles settle more rapidly than small ones and therefore are of greatest concern in areas relatively close to their point of emission to the atmosphere. They dirty horizontal surfaces and produce damage by their abrasive action and sometimes corrosive action.

Emissions from each of the 13 Rubbertown plants are tabulated in Tables 3-3 to 3-11. Most plant operations are described with a flow sheet and a short summary of its processes. Emissions may be identified both on the flow diagrams and the tabular summaries.

It will be noted that in tabular summaries, emissions are grouped into process losses and combustion products. Process losses include those from true processes plus storage and handling losses. In some cases, such as in electric carbide furnace and kiln driers, process and combustion effluents are vented through the same stack, making it necessary to arbitrarily designate the effluent as a process or combustion emission. From this grouping some generalizations may be made for use in future inventories by relating process losses, per se, to the plant's energy consumption. Energy used or production rates (when not company confidential) are given for each plant.

Each major category is divided into those pollutants emitted as gases and vapors and those emitted as particulates. Such a distinction is necessary since certain vaporous emissions frequently become particulate in the atmosphere (e.g., hygroscopic vapors).

A further subdivision of gas and vapor emissions distinguishes between those materials which are permanent (i.e., neither condense readily at atmospheric temperatures nor are hygroscopic), those which have boiling points above 0 degrees C. (condensable), and those which readily combine with water vapor forming fogs and mists (hygroscopic). The limiting temperature of 0 degrees C. for condensables was chosen as being representative of the average minimum atmospheric temperature in Louisville. Condensation of such vapors will occur only if the atmospheric temperature is below their dew point at the point of emission. The dew point will depend on stack concentration. For example, if carbon tetrachloride vapors are emitted from a stack at 25 degrees C. into an ambient atmosphere of 0 degrees C., condensation will theoretically occur in the plume if the carbon tetrachloride concentration is equal to or greater than 4.1 percent. Such effluent concentrations frequently occur in one Rubbertown plant.

Total emissions are classified on the basis of whether they are continuous, intermittent, or seasonal, or a combination of any of these.

In the following, pollution emissions have been tabulated for domestic and commercial sources including a few small industries (Table 3-1), transportation activities (Table 3-2), and for specific industries. Summary tables are presented near the end of this section, followed by findings.

Plants Numbers 1, 10, 11, 12, and 13

These plants are similar in that all are primarily gasoline storage depots, with no manufacturing processes. Losses to the atmosphere are due solely to "breathing" and filling losses from petroleum storage tanks. Table 3-3 summarizes the losses from these plants.

Plant Number 2

Plant 2 is a wood preserving company which treats new lumber for use as railroad ties. Approximately 200,000 ties are processed each year. New wood is dried and aged in the atmosphere for one year before being creosoted. The creosoting process consists of curing in a completely filled sealed chamber at 200 degrees F. and 190-200 psi, followed by extraction under 22 inches mercury vacuum. The resulting equilibrium creosote absorption averages 6-8 pounds per cubic foot. After vacuum treatment the ties are stored in the open for an average of one year for drying. Approximately 275 tons per month of western Kentucky coal are burned for process heating purposes. In addition, approximately 750 tons per month of waste wood are incinerated. A simplified process flow diagram is presented in Figure 3-1. Pollution emissions are tabulated in Table 3-4.

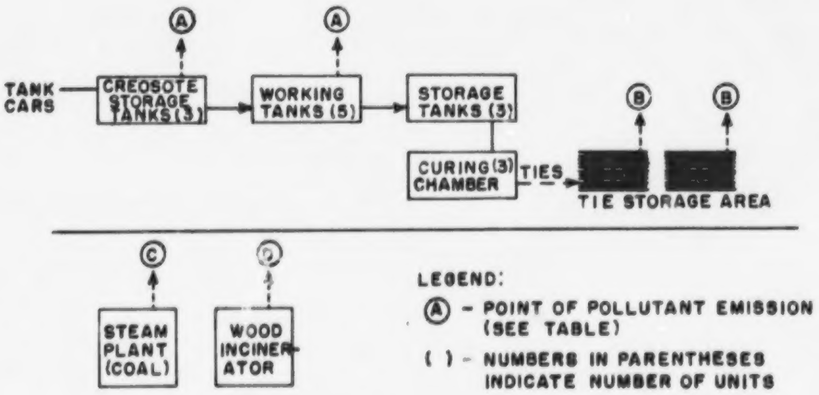


Figure 3-1. SIMPLIFIED FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM PLANT 2 (WOOD PRESERVING PLANT)

Plant Number 3

Plant 3 produces neoprene (chloroprene base synthetic elastomers). Although total production figures are confidential, emissions may be related to energy consumption. The plant burns 16,300 tons of coal per month for steam generation and 75,000 cfm of natural gas for process heating. Overall energy consumption is, therefore, approximately 1.1 x 10^{11} Btu per day. Process flow sheets are company confidential.

The neoprene production process begins in the monovinyl acetylene area with the addition of acetylene to itself, a dimerization, to form vinylacetylene. This is effected by absorption of acetylene in a solution of cuprous chloride and ammonium chloride in hydrochloric acid. Emissions to the atmosphere are minor from the reactors. However, major emissions arise from the burning of divinylacetylene and the purification of the acetylene (Table 3-5 and 3-6).

In the chloroprene area hydrogen chloride then is added to the monovinylacetylene to produce chloroprene. In this portion of the plant the major source of Pollution is the purge column vents which release monovinylacetylene and vinyl chloride. Stripper vents release aldehydes.

In the poly area the chloroprene is emulsified in water with a sodium rosin soap and is polymerized by the action of potassium persulfate. A modifying agent is used to make the polymer more plastic. Dry neoprene then is isolated from the latex by the continuous coagulation of a polymer film on a freeze drum followed by washing and drying. The dry polymer is cut into ropelike sections and bagged. The major contaminants from this poly area are toluene and monovinylacetylene which are emitted from the dryers. Also large quantities of chloroprene come from the aging tank.

Two other processes ancillary to neoprene production exist in this plant, hydrochloric acid manufacture and Freon 22 manufacture. In the acid area the salt-sulfuric acid method is used to produce hydrochloric acid; emissions of hydrogen chloride and chlorine arise from the acid absorbers.

In the Freon area Freon 22 is produced from chloroform and hydrogen fluoride by the action of antimony trifluoride containing pentahalide as catalyst. The major emission is chlorodifluoromethane from the freon scrubber. Emissions originating in each area are tabulated in Tables 3-5 and 3-6.

Plant Number 4

Plant 4 is engaged in the production of synthetic rubber (butadiene-acrylonitrile and butadiene-styrene copolymers) and polyvinyl chloride resins and plastics. Production rates are company confidential. Energy consumption, computed on the basis of 4,270 tons coal per month, is approximately 4.1 x 10^9 Btu per day.

The synthetic rubber process (Figure 3-2) consists of the batch polymerization of the monomers under variable conditions of pressure, temperature, concentration, time, and catalysts, producing a water emulsion of the polymer. The reaction is stopped by inhibitors (blowdown tanks) and the emulsion is then concentrated, coagulated, and dried. The product is shipped in bags or drums.

In the vinyl chloride resin process (Figure 3-3), anhydrous hydrochloric acid is reacted with acetylene in the presence of a catalyst to produce vinyl chloride which is liquefied and distilled at low temperature to eliminate impurities. The monomer is polymerized in the presence of special promoters and the resulting slurry is dried and mixed with plasticizers to form a rubber-like plastic material. Data on pollutants discharged from points of emission shown in Figures 3-2 and 3-3 are tabulated in Table 3-7.

Plant Number 5

Plant 5 is a comparatively small oil refinery processing approximately 7000 barrels of crude oil per day. Major products are gasoline, kerosene, number two and number six fuel oil, and naphtha. The flow sheet (Figure 3-4) indicates the main refining processes. Crude is received by barge, desalted and "topped" for the straight run gasoline. The heavier hydrocarbons are redistilled producing heavy straight run gasoline. Bottoms from this distillation are sold as kerosene or fuel oil or thermally cracked to produce gasolines used in blending. The tops are unifined and reformed in the presence of platinum catalysts. The emissions indicated schematically in Figure 3-4 are tabulated in Table 3-8.

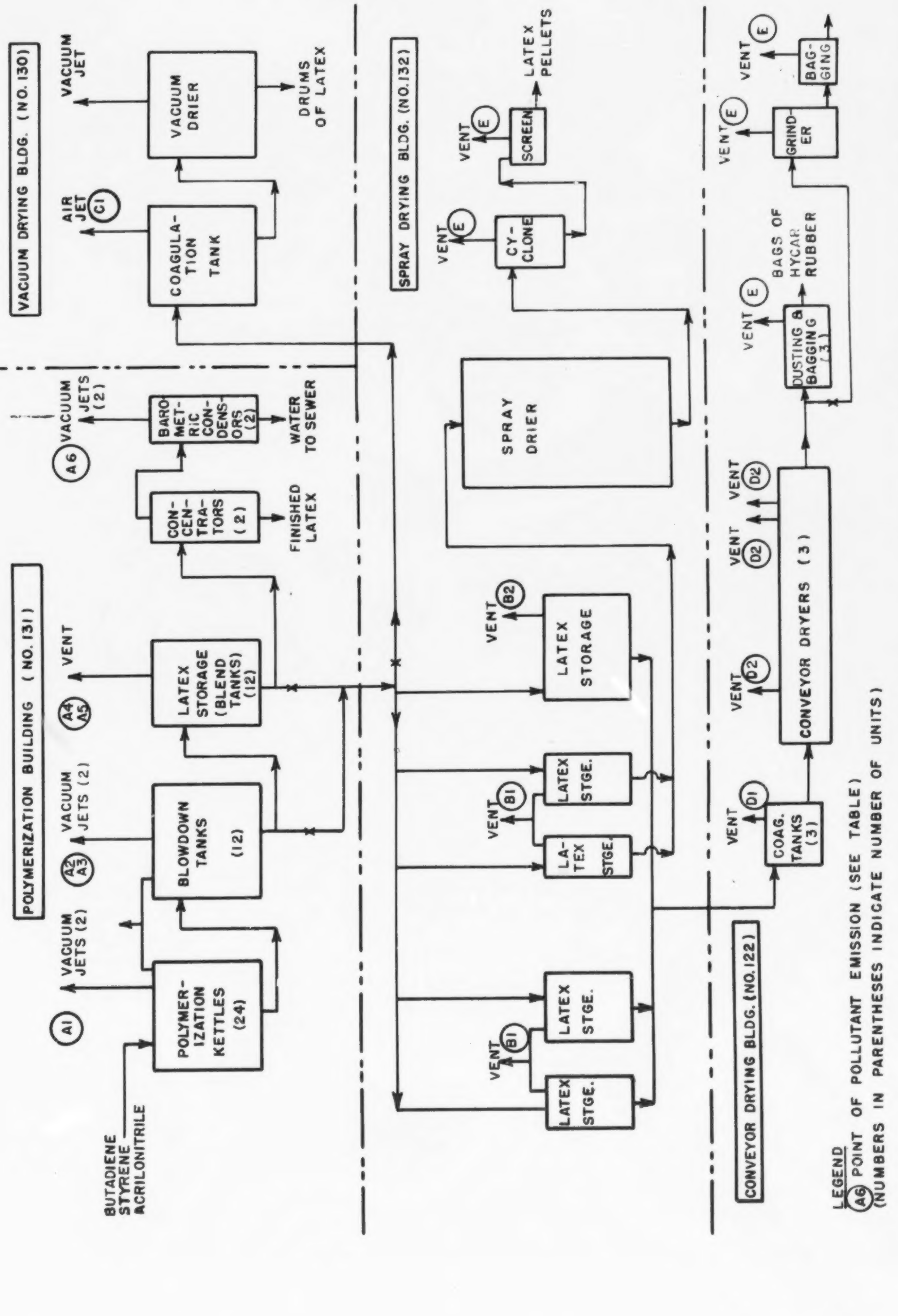

POLYMERIZATION BUILDING (NO.131)
BUTADIENE
STYRENE
ACRILONITRILE
A1
VACUUM JETS (2)
POLYMERIZATION KETTLES (24)
A2 A3
VACUUM JETS (2)
BLOWDOWN TANKS (12)
A4 A5
VENT
LATEX STORAGE (BLEND TANKS) (12)
CONCENTRATORS (2)
FINISHED LATEX
A6
VACUUM JETS (2)
BAROMETRIC CONDENSORS (2)
WATER TO SEWER
VACUUM DRYING BLDG. (NO.130)
AIR JET
C1
COAGULATION TANK
VACUUM JET
VACUUM DRIER
DRUMS OF LATEX
SPRAY DRYING BLDG. (NO.132)
VENT
B1
LATEX STGE.
LATEX STGE.
VENT
B1
LATEX STGE.
LATEX STGE.
VENT
B2
LATEX STORAGE
SPRAY DRIER
VENT
E
CYCLONE
VENT
E
SCREEN
LATEX PELLETS
CONVEYOR DRYING BLDG. (NO.122)
VENT
D1
COAG. TANKS (3)
VENT
D2
VENT
D2
VENT
D2
CONVEYOR DRYERS (3)
VENT
E
DUSTING & BAGGING (3)
BAGS OF HYCAR RUBBER
VENT
E
GRINDER
VENT
E
BAGGING
LEGEND
A6 POINT OF POLLUTANT EMISSION (SEE TABLE)
(NUMBERS IN PARENTHESES INDICATE NUMBER OF UNITS)

Figure 3-2. FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM SYNTHETIC RUBBER PROCESS AT PLANT 4 (SYNTHETIC RUBBER PLANT)

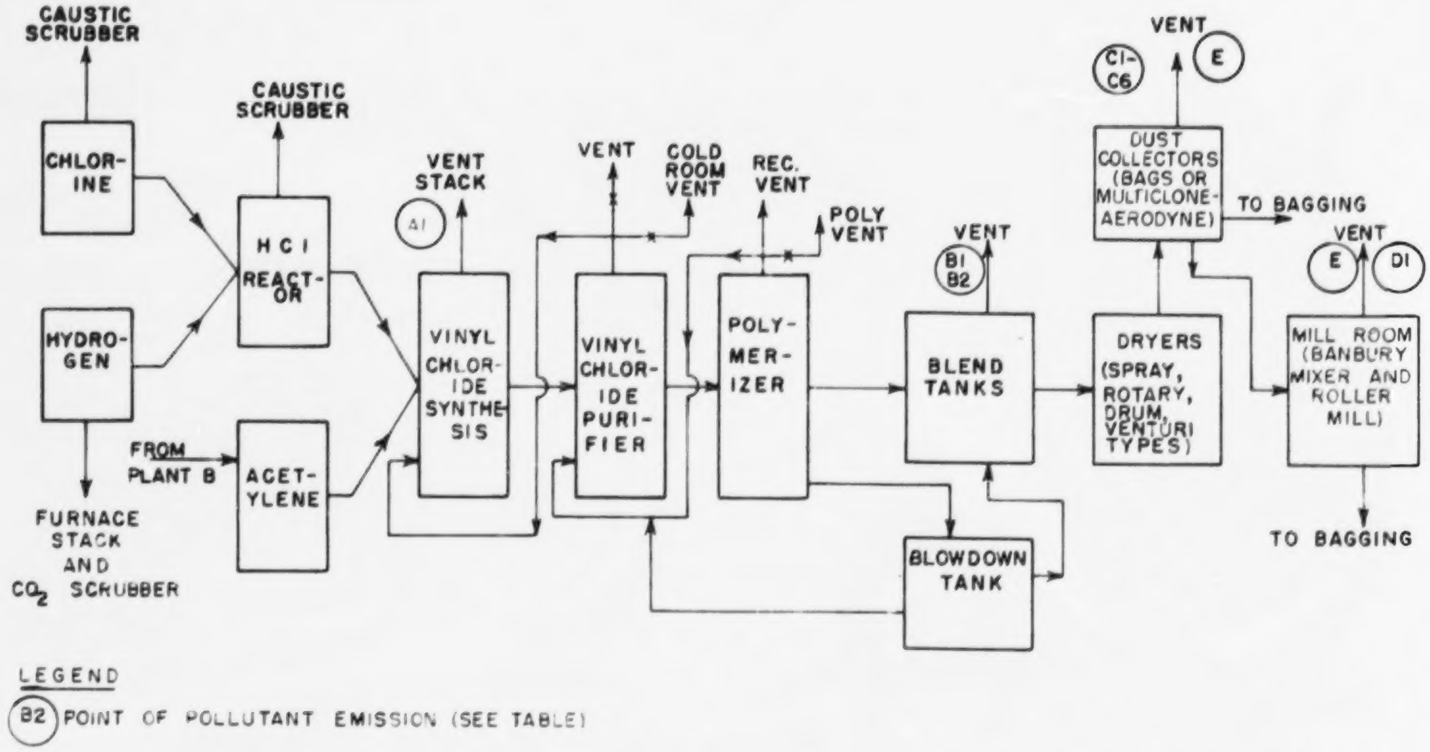

CAUSTIC SCRUBBER
CHLORINE
HYDROGEN
FURNACE STACK AND CO_2 SCRUBBER
CAUSTIC SCRUBBER
HCl REACTOR
FROM PLANT B
ACETYLENE
VENT STACK
A1
VINYL CHLORIDE SYNTHESIS
VENT
COLD ROOM VENT
VINYL CHLORIDE PURIFIER
REC. VENT
POLY VENT
POLYMERIZER
VENT
B1 B2
BLEND TANKS
BLOWDOWN TANK
VENT
C1-C6
E
DUST COLLECTORS (BAGS OR MULTICLONE-AERODYNE)
TO BAGGING
DRYERS (SPRAY, ROTARY, DRUM, VENTURI TYPES)
VENT
E
D1
MILL ROOM (BANBURY MIXER AND ROLLER MILL)
TO BAGGING
LEGEND
B2 POINT OF POLLUTANT EMISSION (SEE TABLE)

Figure 3-3. FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM VINYL CHLORIDE RESIN PRODUCTION AT PLANT 4

Plants Numbers 6 and 7

Plants 6 and 7 are separate installations which generate electric power with coal-burning steam producing equipment. No flow sheets for these operations are necessary. Table 3-9 indicates emissions from each plant. The total coal consumption for the two plants is approximately 2700 tons per day divided about equally between them. Total energy consumption is approximately 7.5×10^{10} Btu per day.

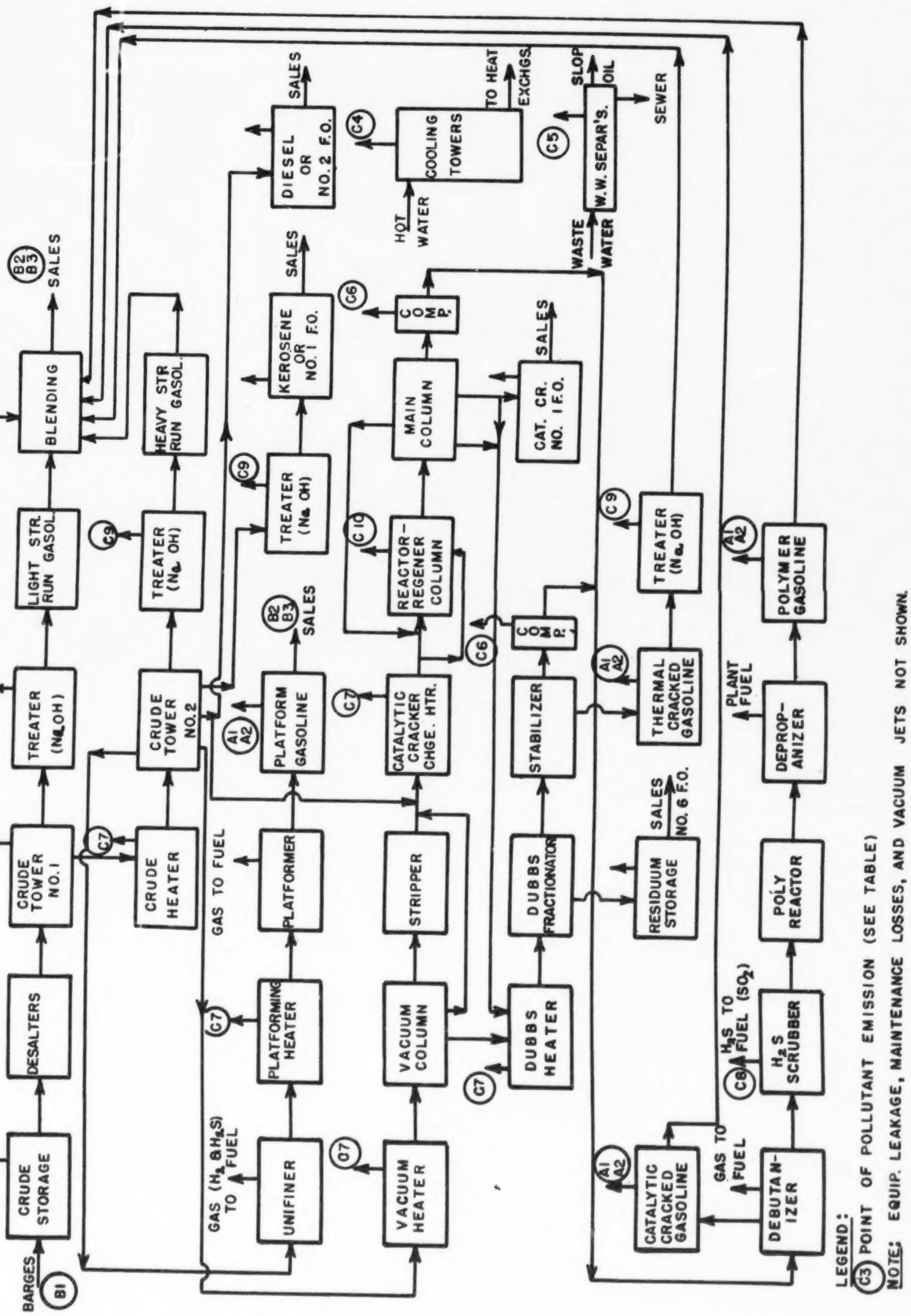
Plant Number 8

Plant 8 produces about 420 tons per day of calcium carbide from petroleum coke and calcined lime. This material, supplemented by 580 tons per day of purchased carbide, is used to produce approximately 9 million cu. ft. of acetylene per day. Figure 3-5 is a simplified flow sheet of both the carbide and acetylene processes. Petroleum coke is crushed, oven-dried, and pre-mixed with calcined lime. The mixture is heated in electric furnaces at 3000 degrees C. for about 45 minutes, poured into carriers and cooled for 24 hours. The cooled carbide is crushed and loaded into hopper-cars and other packaging units for distribution and for acetylene generation. Carbide is released from hoppers into water-filled generators with resulting formation of acetylene. This product is scrubbed and then stored. From this point, part of the acetylene is packaged for sale in the cylinder plant or piped under pressure to local consumers (Plants 3 and 4).

Ancillary processes include a nitrogen plant producing purge gas by fractionation of air, an inert gas plant producing a nitrogen-carbon dioxide mixture from natural gas combustion, and a pilot plant recovering lime by centrifuging and dehydrating process wastes. Table 3-10 is a tabulation of pollutant emissions from this plant.

Plant Number 9

Plant 9 produces carbon tetrachloride, parchloroethylene, and hydrochloric acid using chlorine and propane as primary reactants. On the basis of coal consumption of 1000 tons per month, energy consumption is approximately 9.5×10^8 Btu per day.


BARGES
B1
CRUDE STORAGE
A1 A2
DESALTERS
CRUDE TOWER NO. 1
GAS TO FUEL
TREATER (NaOH)
C9
LIGHT STR. RUN GASOL
BLENDING
Pb (Et)4
SALES
B2 B3
CRUDE HEATER
C7
CRUDE TOWER NO. 2
TREATER (Na OH)
HEAVY STR RUN GASOL.
UNIFINER
GAS (H2 & H2S) TO FUEL
PLATFORMING HEATER
PLATFORMER
GAS TO FUEL
PLATFORM GASOLINE
TREATER (Na OH)
KEROSENE OR NO. 1 F.O.
DIESEL OR NO. 2 F.O.
VACUUM HEATER
VACUUM COLUMN
STRIPPER
CATALYTIC CRACKER CHGE. HTR.
REACTOR-REGENER COLUMN
C10
MAIN COLUMN
COMP.
C6
HOT WATER
COOLING TOWERS
C4
TO HEAT EXCHGS.
DUBBS HEATER
DUBBS FRACTIONATOR
STABILIZER
CAT. CR. NO. 1 F.O.
WASTE WATER
W.W. SEPAR'S.
C5
SLOP OIL
SEWER
RESIDUUM STORAGE
NO. 6 F.O.
THERMAL CRACKED GASOLINE
CATALYTIC CRACKED GASOLINE
DEBUTANIZER
GAS TO FUEL
H2S SCRUBBER
H2S TO FUEL (SO2)
C8
POLY REACTOR
DEPROPANIZER
PLANT FUEL
POLYMER GASOLINE
LEGEND:
C3 POINT OF POLLUTANT EMISSION (SEE TABLE)

NOTE: EQUIP. LEAKAGE, MAINTENANCE LOSSES, AND VACUUM JETS NOT SHOWN.

Figure 3-4. FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM PLANT 5 (OIL REFINERY)

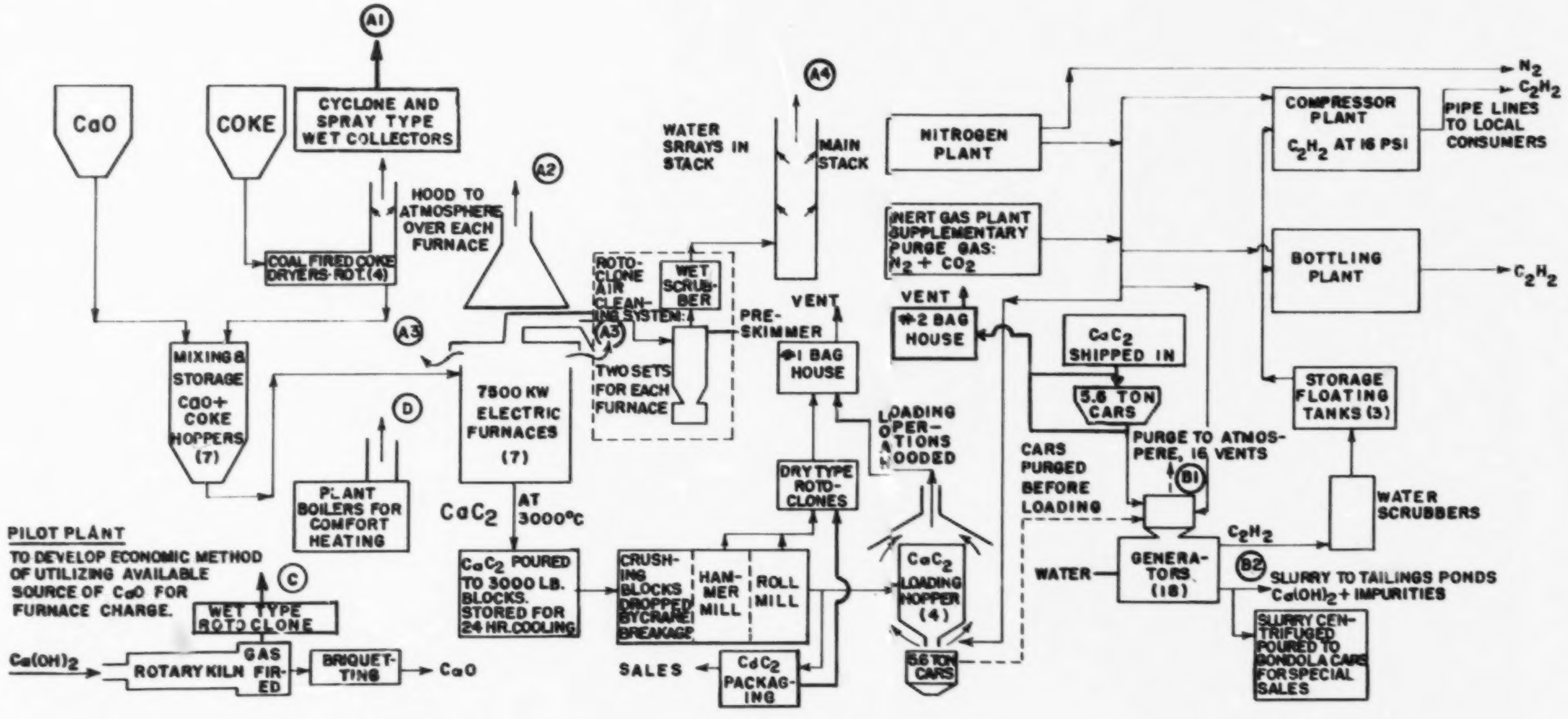

CaO
COKE
CYCLONE AND SPRAY TYPE WET COLLECTORS
A1
HOOD TO ATMOSPHERE OVER EACH FURNACE
A2
COAL FIRED COKE DRYERS-ROT.(4)
A3
MIXING & STORAGE CaO+ COKE HOPPERS (7)
D
PLANT BOILERS FOR COMFORT HEATING
7500 KW ELECTRIC FURNACES (7)
CaC2
AT 3000°C
CaC2 POURED TO 3000 LB. BLOCKS. STORED FOR 24 HR. COOLING
PILOT PLANT
TO DEVELOP ECONOMIC METHOD OF UTILIZING AVAILABLE SOURCE OF CaO FOR FURNACE CHARGE.
C
WET TYPE ROTOCLONE
Ca(OH)2
ROTARY KILN
GAS FIRED
BRIQUETTING
CaO
ROTO-CLONE AIR CLEANING SYSTEM:
WET SCRUBBER
A3
TWO SETS FOR EACH FURNACE
PRE-SKIMMER
WATER SRRAYS IN STACK
MAIN STACK
A4
VENT
#1 BAG HOUSE
CRUSHING BLOCKS DROPPED BY CRANE BREAKAGE
HAMMER MILL
ROLL MILL
DRY TYPE ROTO-CLONES
SALES
CaC2 PACKAGING
LOADING OPERATIONS HOODED
CaC2 LOADING HOPPER (4)
5.6 TON CARS
NITROGEN PLANT
INERT GAS PLANT SUPPLEMENTARY PURGE GAS: N2 + CO2
VENT
#2 BAG HOUSE
CaC2 SHIPPED IN
5.6 TON CARS
CARS PURGED BEFORE LOADING
PURGE TO ATMOSPHERE, 16 VENTS
B1
WATER
GENERATORS (18)
C2H2
B2
SLURRY TO TAILINGS PONDS Ca(OH)2 + IMPURITIES
SLURRY CENTRIFUGED POURED TO GONDOLA CARS FOR SPECIAL SALES
WATER SCRUBBERS
STORAGE FLOATING TANKS (3)
COMPRESSOR PLANT C2H2 AT 16 PSI
BOTTLING PLANT
PIPE LINES TO LOCAL CONSUMERS
N2
C2H2
C2H2

Figure 3-5. FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM PLANT 8 (CALCIUM CARBIDE-ACETYLENE PLANT)

Figure 3-6 is a simplified process flow sheet for the plant. Propane and chlorine are reacted under controlled conditions producing a mixture of hyrdogen chloride, carbon tetrachloride, perchloroethylene, and higher boiling chlorinated hydrocarbons. The products are separated by fractional condensation which separates hydrogen chloride from the less volatile products, and by distillation which separates carbon tetrachloride from perchloroethylene. The products are then purified by stripping (hydrochloric acid) or neutralization (carbon tetrachloride and perchloroethylene). Gaseous hydrochloric acid is piped directly to local consumers; liquid products are shipped in steel drums. The entire process from reactant delivery to completed products takes place within a closed system under a positive pressure of 20 to 50 psi. A few areas have atmospheric vents. These, together with other major sources of emissions, are shown graphically in Figure 3-6 and tabulated in Table 3-11.

SUMMARY OF FINDINGS FROM POLLUTION SOURCE STUDY

General Summary

About 157,000 tons per year of gaseous pollutants are discharged to the atmosphere in western Louisville By far the greatest source of these gases is combustion operations at industrial plants. Industrial processing, combustion operations at domestic and commercial establishments, and transportation activities add lesser but considerable quantities of gaseous pollutants to the atmosphere. Sulfur dioxide constitutes over half of the total gaseous pollutant load. Hydrocarbons and nitrogen oxides, both associated with possible smog forming photochemical reactions, account for about 16 and 11 percent respectively of the total gaseous pollutants. A large variety of other gases are emitted to the atmosphere (Figures 3-7, 8-9).

Coarse particulate materials (>1μ in size) are emitted from sources in western Louisville at the rate of about 14,000 tons per year. Industrial combustion operations account for the majority of such emissions, with one industrial process accounting for much of the remainder (Figure 3-9).

While only about 1700 tons per year of fine particulate matter (<1μ in size) is emitted to the atmosphere, such material is important because of its ability to obscure vision. Combustion of coal in domestic and commercial establishments is responsible for emission of the greatest quantity of fine particles but other types of sources also contribute. (Figure 3-9).

Emissions from Industrial Plants

Gases. Industrial plants discharge about 114,300 tons of gaseous pollutants per year to the atmosphere from combustion operations. About 22,000 tons per year arise from industrial processes. Principal emissions from combustion operations include 82,000 tons per year of sulfur dioxide, 17,000 tons of nitrogen oxides, and 10,000 tons of sulfur trioxide. Principal sources of these gases are Plants 3, 6, and 7. (Figures 3-8, 9).

Principal processing losses are hydrocarbons primarily from gasoline storage depots (Plants 1, 10, 11, 12, 13) and Plant 5; acetylene primarily from Plant 8; hydrogen chloride primarily from Plant 3; and sulfur dioxide primarily from Plant 8. These four gases constitute over half of the losses from industrial processes. These, plus toluene from Plant 3, creosote vapors from Plant 2, and vinyl chloride from Plants 3 and 4 represent about three fourths of total processing losses (Figure 3-7).

Particulate matter. Combustion operations at industrial plants give rise to about 7700 tons per year of coarse particles (>1μ in size) and about 400 tons of fine particles (<1μ). Over 85 per cent of these coarse particles are emitted by Plants 3, 6, and 7. Plants 6 and 7 are the sources of most of the fine particles (Figure 3-8).

Particulate emissions from industrial processes are due almost entirely to Plant 8. A total of 5250 tons per year of coarse particles and 30 of fine particles are emitted (Figure 3-7). A large part of the material is calcium carbonate.

Emissions From Domestic and Commercial Establishments

Most of the gaseous pollutants and nearly all of the particulate pollutants from domestic and commercial establishments arise from coal fired units (Table 3-1). Sulfur dioxide is by far the most common pollutant. Hydrocarbons, oxides of nitrogen, inorganic chloride, and organic acids are also emitted in

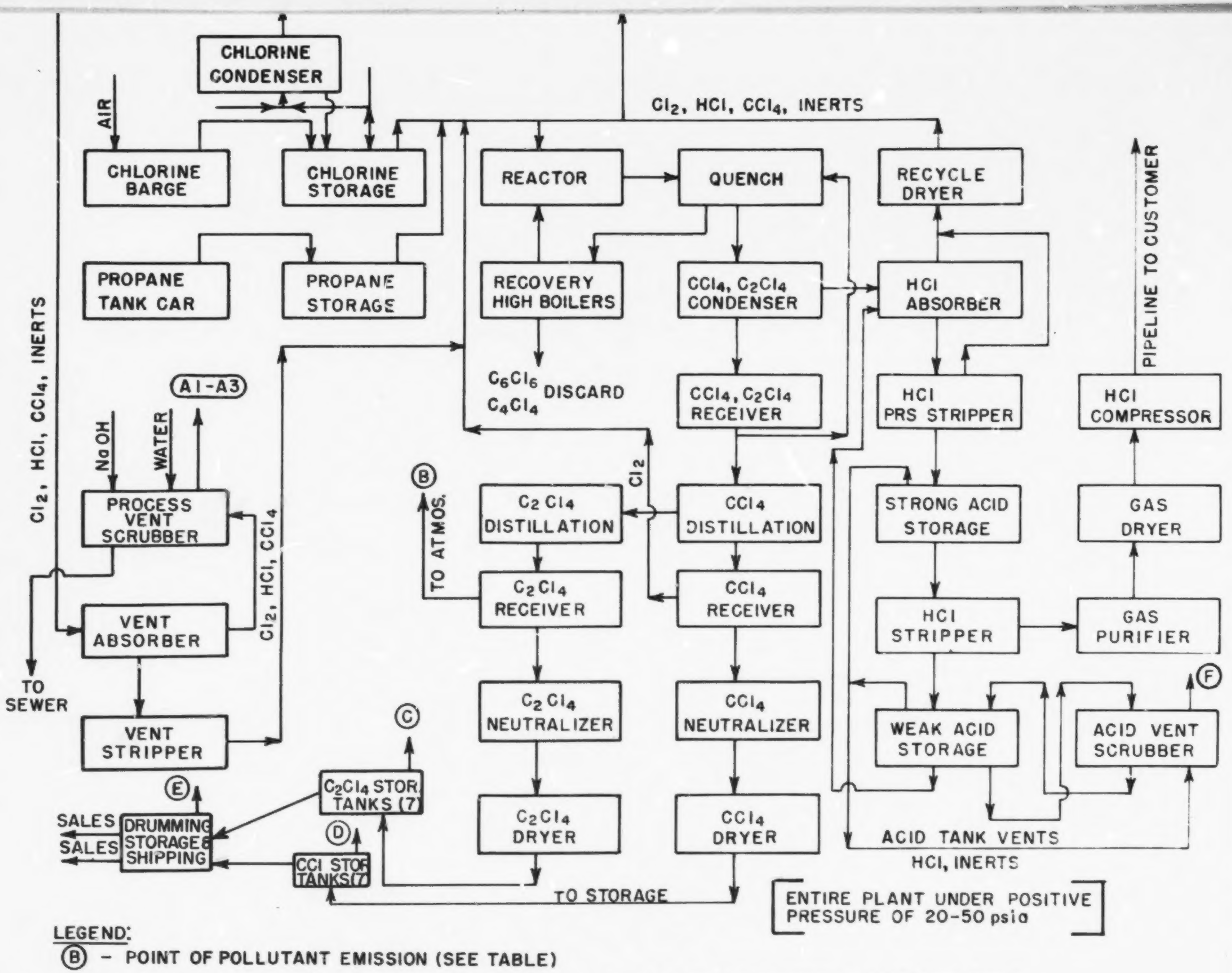
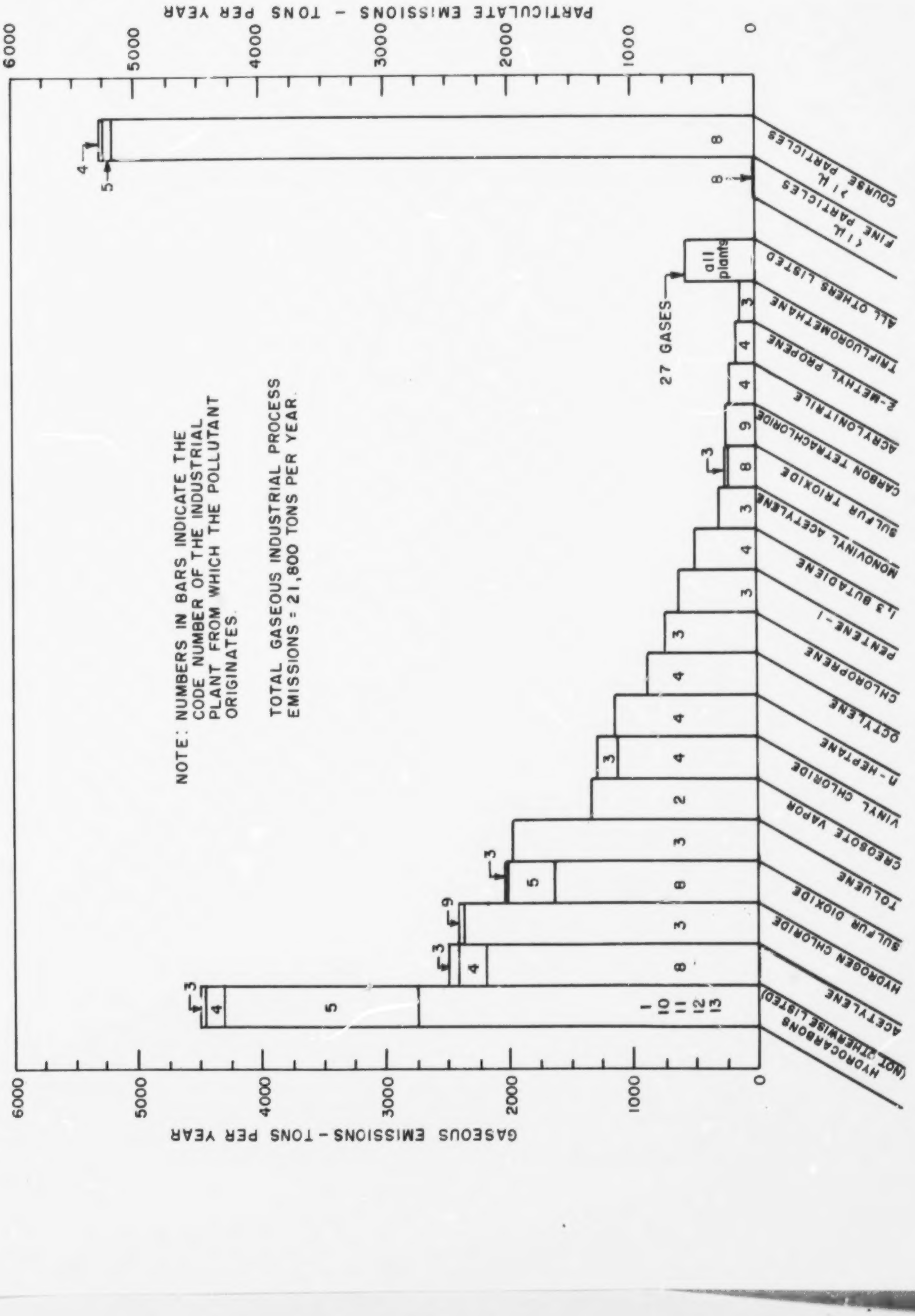

CHLORINE CONDENSER
AIR
CHLORINE BARGE
CHLORINE STORAGE
PROPANE TANK CAR
PROPANE STORAGE
Cl2, HCl, CCl4, INERTS
REACTOR
QUENCH
RECYCLE DRYER
RECOVERY HIGH BOILERS
CCl4, C2Cl4 CONDENSER
HCl ABSORBER
C6Cl6 C4Cl4 DISCARD
CCl4, C2Cl4 RECEIVER
HCl PRS STRIPPER
HCl COMPRESSOR
PIPELINE TO CUSTOMER
Cl2, HCl, CCl4, INERTS
NaOH
WATER
A1-A3
PROCESS VENT SCRUBBER
Cl2, HCl, CCl4
VENT ABSORBER
TO SEWER
VENT STRIPPER
B
TO ATMOS.
Cl2
C2Cl4 DISTILLATION
CCl4 DISTILLATION
STRONG ACID STORAGE
GAS DRYER
C2Cl4 RECEIVER
CCl4 RECEIVER
HCl STRIPPER
GAS PURIFIER
C2Cl4 NEUTRALIZER
CCl4 NEUTRALIZER
WEAK ACID STORAGE
ACID VENT SCRUBBER
F
C
C2Cl4 STOR. TANKS (7)
E
D
SALES
SALES
DRUMMING STORAGE & SHIPPING
CCl STOR TANKS(7)
C2Cl4 DRYER
CCl4 DRYER
TO STORAGE
ACID TANK VENTS
HCl, INERTS
ENTIRE PLANT UNDER POSITIVE PRESSURE OF 20-50 psia
LEGEND:
B - POINT OF POLLUTANT EMISSION (SEE TABLE)

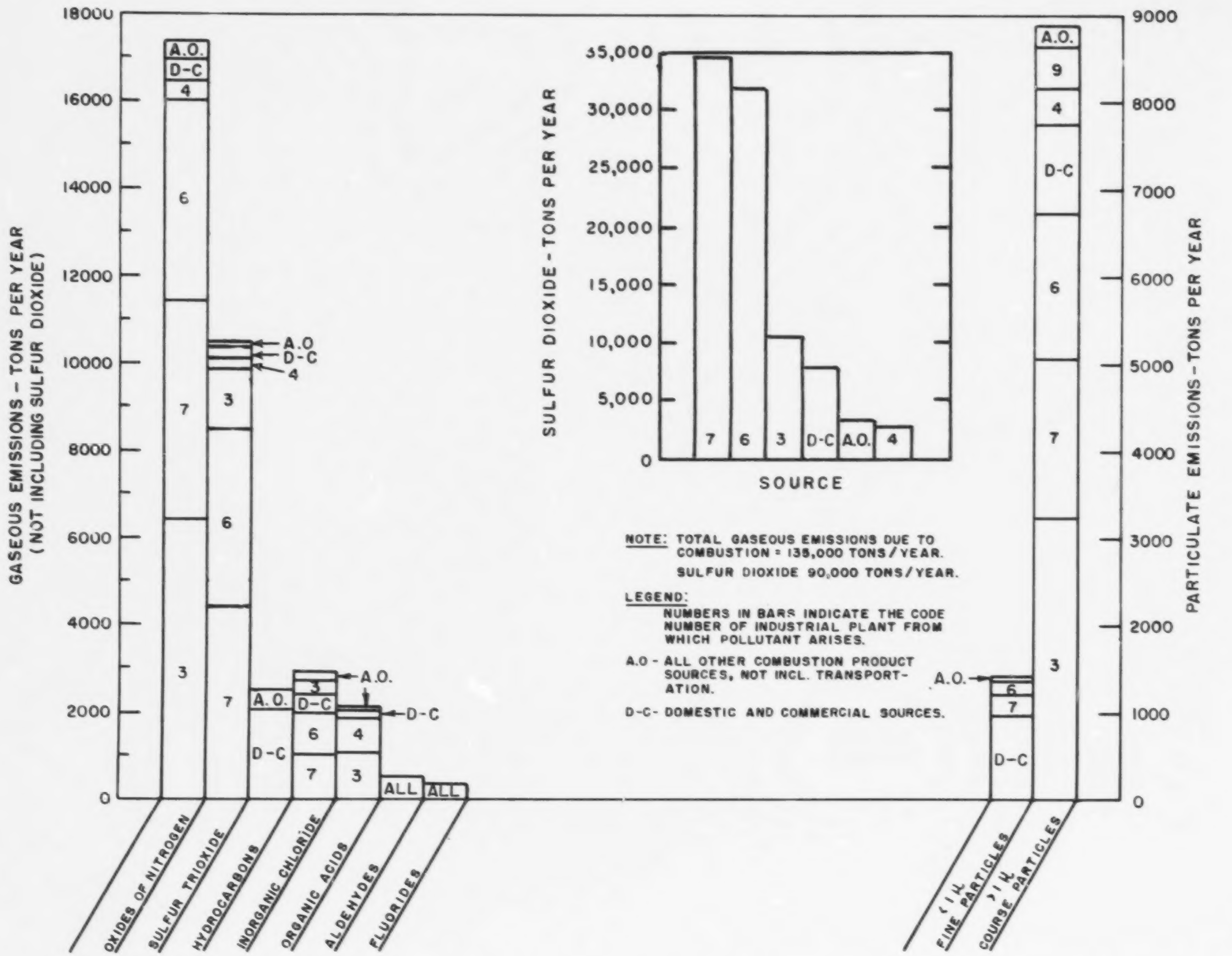
Figure 3-6. FLOWSHEET INDICATING POINTS OF POLLUTANT EMISSION FROM PLANT 9 ($CC1_4$; C_2C1_4; AND HC1 PRODUCTION)



NOTE: NUMBERS IN BARS INDICATE THE CODE NUMBER OF THE INDUSTRIAL PLANT FROM WHICH THE POLLUTANT ORIGINATES.

TOTAL GASEOUS INDUSTRIAL PROCESS EMISSIONS = 21,800 TONS PER YEAR.

Figure 3-7. SUMMARY OF POLLUTANT EMISSIONS FROM INDUSTRIAL PROCESSES (NOT INCLUDING COMBUSTION EMISSIONS)



NOTE: TOTAL GASEOUS EMISSIONS DUE TO COMBUSTION = 135,000 TONS/YEAR.
SULFUR DIOXIDE 90,000 TONS/YEAR.

LEGEND:
NUMBERS IN BARS INDICATE THE CODE NUMBER OF INDUSTRIAL PLANT FROM WHICH POLLUTANT ARISES.
A.O - ALL OTHER COMBUSTION PRODUCT SOURCES, NOT INCL. TRANSPORTATION.
D-C - DOMESTIC AND COMMERCIAL SOURCES.

Figure 3-8. PRODUCTS OF COMBUSTION EMITTED TO THE ATMOSPHERE (NOT INCLUDING TRANSPORTATION SOURCES)

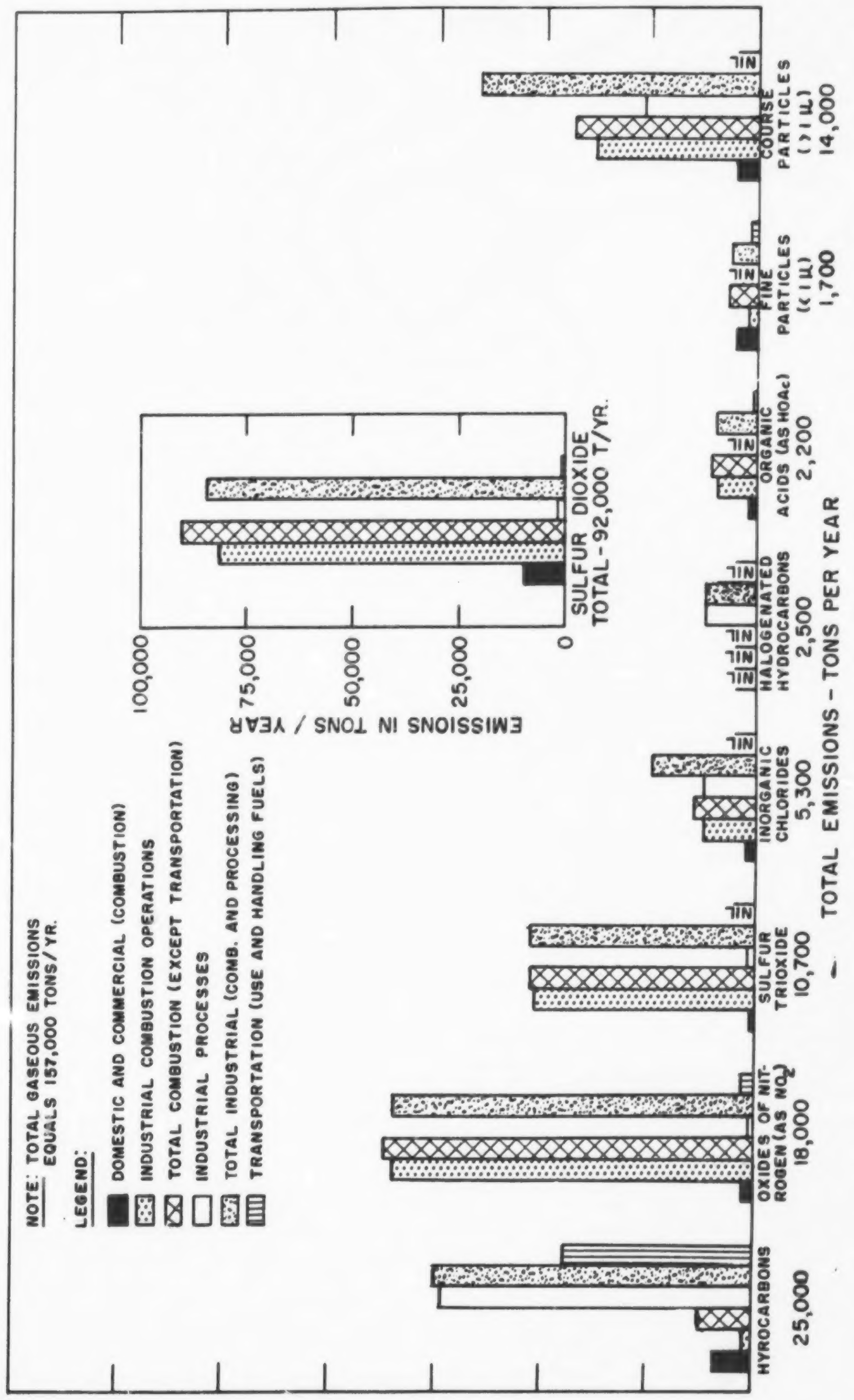


Figure 3-9. SUMMARY OF PRINCIPAL POLLUTANT EMISSIONS FROM VARIOUS TYPES OF SOURCES

considerable quantities. Nearly 1000 tons per year each of coarse and fine particulate matter are discharged from these coal burning units and they are no doubt important factors influencing air quality during the space heating season.

Emissions Due to Transportation Activities

The only pollutant arising from transportation activities in large quantities (in relation to other sources) are hydrocarbons (Figure 3-9). Nearly 9,000 tons per year are released to the atmosphere, largely from use of gasoline in automobiles and other vehicles. The remainder comes from gasoline handling and use of diesel fuel (Table 3-2). Noteworthy amounts of nitrogen oxides, and small quantities of other gases are released. A significant part (13 per cent) of the total emissions of fine particles is due to operation of motor vehicles (Figure 3-9).

Relative Magnitude of Sources of Pollutants

Total gaseous pollutants. Of the total gaseous pollutants discharged to the atmosphere, over 70 percent arises from combustion operations at industrial plants and over ten percent arises from industrial processes. Combustion operations at domestic and commercial establishments and transportation activities each contribute about six percent of the total.

Sulfur dioxide. Combustion operations at three power plants (3, 6, and 7) account for the vast majority of sulfur dioxide emissions. Domestic and commercial combustion operations account for less than ten percent of the total and transportation activities less than one per cent. Industrial processes add about two percent of the total (Figure 3-7 and 3-9).

Hydrocarbons. Industrial processes are responsible for about 56 percent of the total emission of hydrocarbons. The largest sources are acetylene from Plant 8, gasoline vapors from bulk storage depots (Plants 1, 10, 11, 12, 13), various hydrocarbons from Plant 5, and toluene from Plant 3. Transportation activities (use and handling of gasoline) contribute about 36 percent while domestic and commercial combustion operations emit about 7 percent of the total. Industrial combustion operations add less than one percent of the total.

Oxides of nitrogen. The great majority of these gases are emitted by industrial combustion operations (largely Plants 3, 6, and 7). Transportation activities, domestic and commercial combustion operations, and industrial processing add about 4, 3, and one-fourth percent respectively,

Coarse particulates ($>1\,\mu$ in size). Combustion operations at industrial plants are the source of about 55 percent of total coarse particulate matter emissions, with Plant 3 alone accounting for about 23 percent of the total and Plants 6 and 7 contributing about 12 percent each. Industrial process emissions account for about 38 percent of the total, nearly all of which arises from Plant 8.

Fine particulates ($<1\,\mu$ in size). Combustion of coal in domestic and commercial establishments causes emission of nearly 58 percent of the total emission of fine particulate matter. Industrial combustion operations (largely Plants 6 and 7), and transportation activities emit about 23 and 18 percent respectively of the total.

CLIMATOLOGICAL STUDY

General Climatological Description

The location of Louisville in the southeastern quadrant of the North American land mass results in a modified continental climate, with warm, rather humid summers, and cool winters. Precipitation, in the form of summertime showers and thundershowers, and winter time rains (and occasional snows) occurs principally when moist air moves northward and northeastward from the Gulf of Mexico. Surface wind direction is quite variable during all seasons of the year with southerly winds most frequently observed during all months except during the late summer months, when northerly winds are observed with approximately the same frequency. Average hourly wind speed determined from airport observations is near ten mph. in the winter months, varying from near eight mph. in the early morning hours to 12 mph. during the afternoon. During the summer months, the average hourly speed is about seven mph., with a variation of from four mph. during the early morning to ten mph. during the afternoon. Average wintertime relative humidity varies from 60-70 per cent during the afternoon hours to about 80 per cent during the night hours; summertime readings vary from 50 percent to over 80 per cent. A summary of some of these data is given in Table 3-12 and Figure 3-10.

Meteorological conditions to be found during any given interval of time are subject to a constantly changing field of weather influences, and therefore deviations from a longer period normal are to be expected in the values of elements measured during any partial interval. The seasonal change of the atmospheric circulation, following a more or less periodic variation, is the dominant factor in the changing weather picture in any locality, with a superimposed daily variation because of the alternating periods of day and night. The mean annual variation of the general circulation may be looked on as a relaxation of the prevailing west-to-east motion of the bulk of the atmosphere and a contraction of the circumpolar vortex from winter to summer. As this relaxation takes place, the main zone of temperature contrast between warm and cold air masses shifts northward, air mass contrasts are diminished, and the prevailing tracks of high and low pressure centers also shift northward. During the winter months, cool air masses from the Pacific Northwest are most frequently present in the Louisville region. Cold Canadian air is not uncommon, although usually the cold air masses become diluted with cool Pacific air as they move southward and spread over the eastern United States. Wintertime temperatures below 0 degrees F are observed in Louisville, but only with an average frequency of once or twice a season. Warm air masses from the Gulf of Mexico are generally observed in conjunction with developing low pressure centers moving northeastward to the west of Louisville, and are therefore accompanied by cloudy, showery weather. Snow or rain occurs as low pressure centers move eastward to the south of Louisville. The sequence of passing weather systems and air masses results in comparatively large day-to-day temperature changes.

In the summer months, Louisville is most frequently under the influence of the semi-permanent sub-tropical high pressure center over the Atlantic which produces a flow of warm air from the south and southwest. The paths of low pressure centers normally are well to the north, and their influence on the Louisville region is felt as the surges of cooler air following these lows spread southeastward. As these cooler air masses approach, showers and thundershowers usually develop in the warm, humid air in advance of the cool air: these showers often develop whether or not the cool air actually reaches as far southward as Louisville.

The spring transition from winter to summer weather occurs during April and May. The general circulation of the atmosphere and the contrasts between cool and warm air masses are still rather strong, and the sun's heating is also strong. It is therefore during the spring months that the most violent local storms (hail storms, thundersqualls, and tornadoes) are observed. The greatest frequency of stronger daytime winds, resulting from the strength of the general air flow combined with the convective mixing because of solar heating, is observed in April.

The fall transition is of a different character. The circumpolar vortex gradually increases in strength from August on through January or February, but the mean position of the main zone of contrast between air masses over the eastern part of North America remains at nearly the same latitude through October. In November, the strengthening vortex usually shifts its position, so that Louisville is near the mean position of the main thermal contrast, which is reflected in a rather abrupt change to wintertime weather characteristics.

The prevailing weather during any individual month may not be the weather which is typical of that month, because variations from the mean seasonal circulation are the rule rather than the exception. The variations most commonly result in a repetition of a particular weather sequence which may in one month produce warm wet weather, another cold weather, etc. As a general rule, therefore, the conditions observed during any given month should not be assumed to represent the conditions in that same month in any other year, nor should they be assumed to represent a normal or average. Gross indications of the relationships between normal weather conditions and those which occurred during the air pollution study are shown in Table 3-12 and Figure 3-10. It may be noted that for most months, the frequency of lighter winds was below average, and the monthly average wind speed was correspondingly above average. The number of days with measurable precipitation was somewhat above average, as was the percentage of possible sunshine. Consideration of these

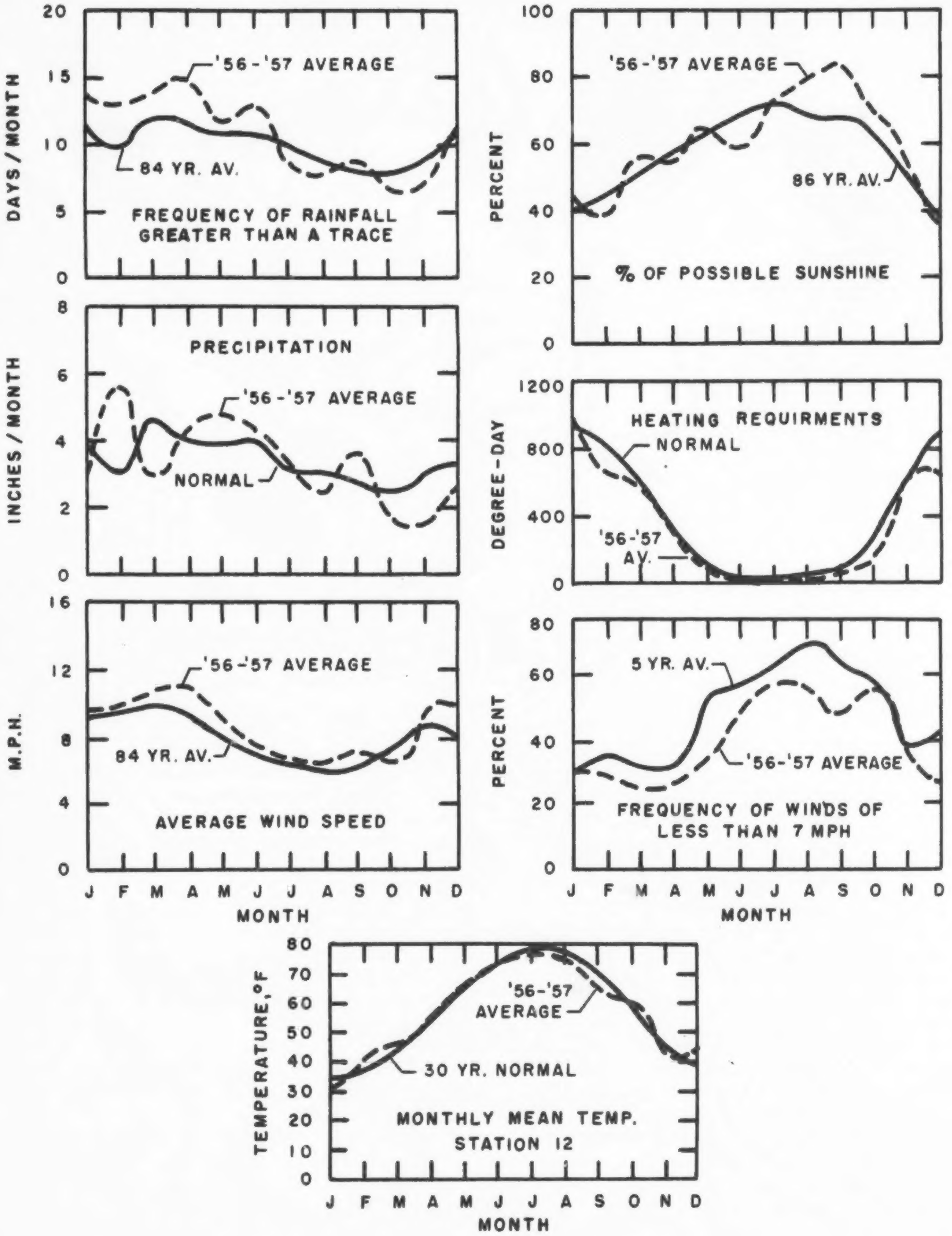


Figure 3-10. RELATIONSHIP OF NORMAL WEATHER CONDITIONS TO THOSE OCCURRING DURING THE STUDY

factors together with the weather sequences that produced them, leads to the conclusion that the conditions for dissipation of air pollutants were somewhat better than average during the period of the study; the study period should not be characterized as abnormal, however. Space heating requirements as indicated by the number of degree days, were below normal, a factor tending to result in lower than normal emission of pollutants due to use of fuel.

Detailed Climatological Description

The topography of the Louisville area is the primary determinant of local variations in meteorological elements. The city is located in an irregularly shaped valley which extends from south-southwest to north-northeast, from Kosmosdale through western Louisville and northward into Indiana along Silver Creek. The valley is broadened by an extension to the east near its center, and the city is located more or less in the middle of the broadened portion of the valley. The western edge of the valley is defined by the range of hills west of the Ohio River, in Indiana. To the east, the land rises more gradually into gently rolling hills.

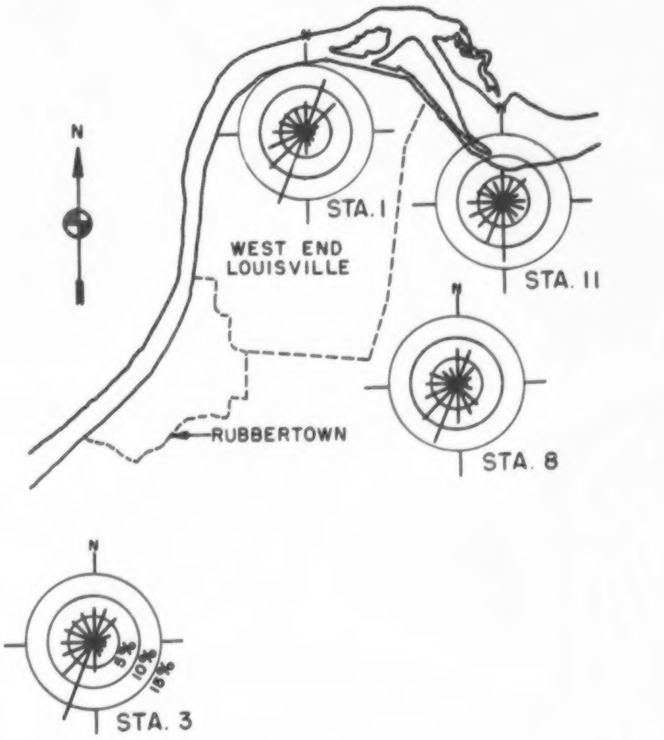


Figure 3-11. WIND DIRECTION FREQUENCIES AT FOUR STATIONS

Air flow over the western part of Louisville tends to follow the main orientation of the valley. Thus, stations 1 and 3 show a maximum frequency of winds from the south-southwest, with a secondary maximum from the north-northeast (Figure 3-11). At Standiford Field (Station 12) the winds do not show this preference, but instead show a relatively high frequency of south-easterly winds, and a somewhat higher frequency of northwesterly winds, representing, in part, channelling along the minor axis of the valley. There are also differences in the speed of flow over the area, with relatively lighter mean wind speeds over the western parts of Louisville than elsewhere (Table 3-13) which are probably caused by the blocking influence of the range of hills across the river. Detailed comparisons are difficult, because differences in recorded mean wind speed between stations are caused in part by the differing equipment and recording methods employed. The differences in the speed and direction of flow occur principally during periods of stability of the atmosphere, in conjunction with a temperature inversion which greatly reduces vertical mixing of the air. When an inversion develops, the air near the surface is in effect uncoupled from the moving air stream at higher levels, and will tend to cease moving because of ground friction, in the absence of any other force. Under these conditions, small differences of air pressure caused by local differences of air temperature may become sufficient to impart a small motion to the air, acting to cause the air at the surface to drift from cooler towards warmer areas. During the night hours, the most urbanized areas tend to be the warmest. Thus station 3 records the lowest average minimum temperature, and station 8 the highest of the stations of the same type and elevation (Table 3-14). Standiford Field minima are slightly higher than minima at station 8, but conditions of observation differ. It is estimated from the limited period of record available that the minimum temperatures at the WHAS-TV tower site (Station 11) average 2 to 4 degrees warmer than at the airport. The influence of this urban temperature gradient on the air flow is to cause a tendency for air to converge towards the most built-up portions of the city where air will tend to rise. When stable, light wind conditions develop with a general flow (determined by the TV tower winds) from a southwest direction, station 3 will show a wind from south-southwest, and station 1 from south-southwest or southwest, with the wind speed at station 3 higher than at 1. Station 12 will show a light southeast flow, and station 8 may show either the southwesterly component as shown by stations 1 and 3, or the southeasterly component shown by station 12. Occasionally, station 1 winds may cease entirely, and the flow then reverse to come from the northerly direction.

With a general flow from the northeast, the development of stable light wind conditions will show station 1 and 3 winds predominantly from the north-northeast, but with station 1 wind speed higher; station 3 winds will often become very light and variable, and show a slight westerly component on some occasions. Station 12 winds become south-easterly. Station 8 winds may come from almost any direction under such conditions. Again, the air flow pattern is of a convergence towards the urban areas.

The development of stable light wind conditions is most frequently observed during the summer months because of the greater frequency of clear night-time skies and the lower average wind speeds. Other local air flow patterns may occur from time to time, but there is little direct evidence of their existence.

Stations 10 and 13 were located on higher ground to obtain, if possible, temperature data which would provide an indication of vertical temperature gradients, and thus give a measure of thermal stability. A comparison between recorded temperatures at these stations (Table 3-14) and temperatures recorded at lower elevations does not give this indication, however, because temperatures at both stations are influenced by their surroundings. Although there are many occasions when temperature differences between high and low elevation stations do provide an indication of free-air thermal stability, individual differences cannot be used unless carefully selected. Mean differences of temperature extremes do provide a general indication of the mean atmospheric stability, as illustrated in Figure 3-12. Mean summer minimum temperatures show (except for station 10) an increase of temperature with elevation; mean summer maxima show (except for station 13) a decrease of temperature with height at approximately the adiabatic, or neutral stability, rate. Winter maxima show an adiabatic decrease with height and winter minima are not much different, illustrating the greatly reduced diurnal amplitude of the variation of stability during the winter.

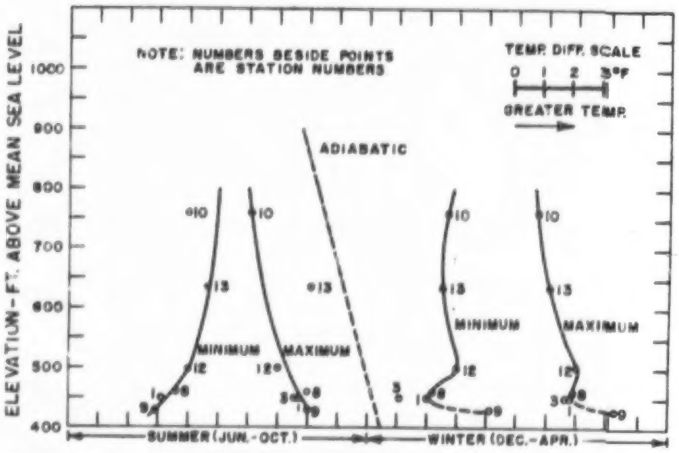


Figure 3-12. DIFFERENCES OF MONTHLY-AVERAGE MAXIMUM AND MINIMUM TEMPERATURES WITH ELEVATION

The TV tower temperature difference measurements made over a limited period (Figure 3-13) indicate that, on the average, a surface-based inversion does not develop at any hour of the night, although an inversion aloft does develop. The built-up areas around the TV tower site are warmer than the less built-up areas at other network stations, particularly during the evening hours, inhibiting the formation of a surface based temperature inversion. However, since a mean inversion does develop above the lower levels, it is likely that mechanical eddies caused by air flow around buildings, etc. contribute an inhibiting effect towards inversion formation.

Precipitation was measured at stations 1 and 3, in addition to the regular measurements made at Standiford Field (Table 3-13). There are appreciable month-to month differences in the relative amounts collected at these locations, but the differences are not consistent enough to indicate any normal difference. The data are illustrative of the large point-to-point variability of rainfall.

The record of solar radiation (Table 3-13) shows a large seasonal variation in average daily radiation received, with the predominant influence being duration of daylight and the sun's elevation, modified by the amount of cloudiness. On some individual days, there is

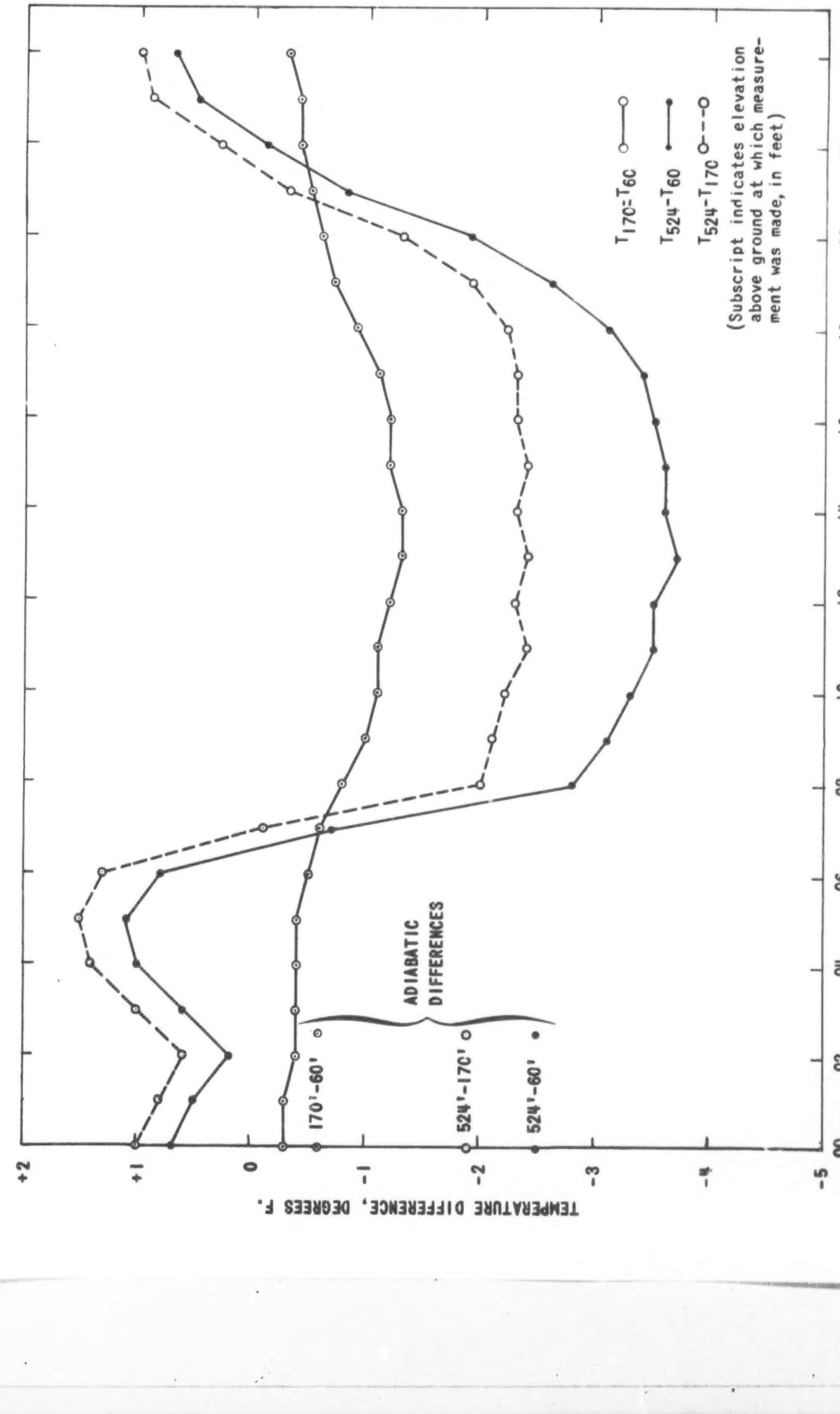


Figure 3-13. AVERAGE HOURLY TEMPERATURE DIFFERENCES FROM WHAS TV TOWER (STATION #11) MEASUREMENTS JULY 30 - AUGUST 23, 1957

a suggestion that the amount of radiation received is reduced by air-borne pollutants, but there is no simple reference by which to measure this potential effect.

Visibility observations were taken for several months at 0800 CST from the study office in West End Louisville (4000 Michigan Drive). The time of observation was near the normal hour of maximum reduction of visibility by smoke and haze. A comparison with concurrent visibility observations made at Standiford Field (Table 3-15) shows a considerably higher frequency of low visibility at the west end location than at the airport. The conditions of observation at the west end location were such that visibilities there were under-estimated in comparison with the visibility that would have been obtained had there been sufficient check points in all directions from the location. This bias, although real, is not great enough to invalidate the large differences between visibilities observed at the two locations.

Summary of Findings from Climatological Study

During the bulk of the time, there are only slight systematic differences of air flow in the vicinity of Louisville. The principal difference is the blocking effect of the hills across the river in Indiana, which reduces the wind speed in the lee of the hills, and tends to turn the air flow to parallel the range of hills. This influence is observed in the western parts of Louisville. Stable conditions show a tendency for a convergence of surface air flow towards the most built-up portion of the city. This flow is most probably confined to the lowest few hundred feet above the surface; there is little evidence for its existence at the level of the TV tower wind measurements. Meteorological conditions which prevailed during the period of the study differed little from normal conditions. Wind movement, precipitation, and percent possible sunshine were somewhat above average and heating degree days were somewhat below average. These departures from average conditions would tend to cause pollution levels to be lower than under average weather conditions.

Average hourly wind speed is near ten mph in winter months and about seven mph in the summer. Wind direction is quite variable during all seasons of the year with southerly winds most frequent during all months except during late summer, when northerly winds occur with about the same frequency.

Louisville has hot humid summers and moderately cold winters. Temperature inversions occur in Louisville as they do in most places. Limited vertical temperature gradient data from instruments mounted on a TV tower indicate that surface based inversions do not occur in the downtown area during the summer but that inversions do develop aloft in that season.

TRACER STUDIES

Tracer studies were conducted to show the effect of stack height and meteorological variables on dispersion of pollutants from Rubbertown over the western part of Louisville and to demonstrate that gases and fine particles arising in Rubbertown can reach ground level in the western part of Louisville. Seven tracer runs were made. In two, tracer material was released at an elevation of 40 feet above ground and in five, it was released 250 feet above ground. A figure and description of each run follows (Figure 3-14). On each one, the surface wind (average of stations 1 and 7) is shown as a solid arrow. The wind indicated by instruments located 524 feet above ground on the TV tower (station 11) are shown as a dashed arrow. Arrow length represents the distance travelled by the wind during a half-hour interval. The dashed lines represent limits within which it was expected that 96-98 percent of the tracer material would reach ground level.

The time interval considered in determining wind parameters varied, depending on recorded wind speeds and on changes of air flow with time. Generally, the interval considered began with the start of release of the tracer, and continued for the length of time required for an air parcel to travel from the release point to the outer sampling arc (a distance of about four miles). Cases in which this travel time was more uncertain because of relatively larger differences of wind speed between surface and TV tower measurements were resolved by taking a longer interval (towards the upper limit of the range of probable travel time) over which parameters were determined. In the majority of cases, determination of average values was made by averaging wind directions and speeds individually. In two cases (runs 5 and 7) the change of surface wind with time was too great to permit use of this averaging method and still obtain sufficient accuracy; two surface wind arrows are shown for these runs. In one case (run 3) the azimuthal change of wind was so great that it was

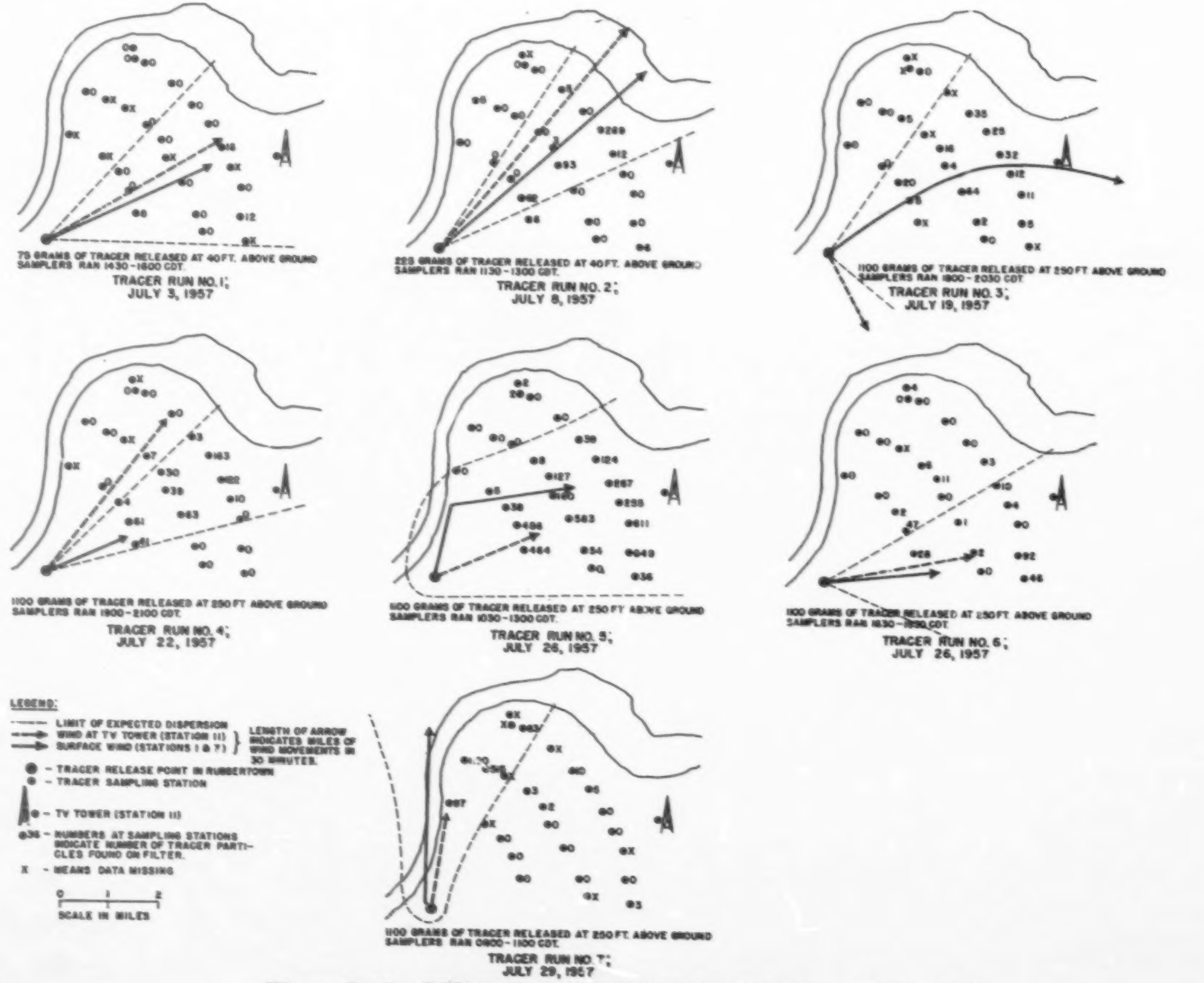

75 GRAMS OF TRACER RELEASED AT 40 FT. ABOVE GROUND
SAMPLERS RAN 1430-1600 CDT.
TRACER RUN NO. 1;
JULY 3, 1957
225 GRAMS OF TRACER RELEASED AT 40 FT. ABOVE GROUND
SAMPLERS RAN 1130-1300 CDT.
TRACER RUN NO. 2;
JULY 8, 1957
1100 GRAMS OF TRACER RELEASED AT 250 FT. ABOVE GROUND
SAMPLERS RAN 1800-2030 CDT.
TRACER RUN NO. 3;
JULY 19, 1957
1100 GRAMS OF TRACER RELEASED AT 250 FT. ABOVE GROUND
SAMPLERS RAN 1900-2100 CDT.
TRACER RUN NO. 4;
JULY 22, 1957
1100 GRAMS OF TRACER RELEASED AT 250 FT. ABOVE GROUND
SAMPLERS RAN 1030-1300 CDT.
TRACER RUN NO. 5;
JULY 26, 1957
1100 GRAMS OF TRACER RELEASED AT 250 FT. ABOVE GROUND
SAMPLERS RAN 1630-1830 CDT.
TRACER RUN NO. 6;
JULY 26, 1957
1100 GRAMS OF TRACER RELEASED AT 250 FT. ABOVE GROUND
SAMPLERS RAN 0900-1100 CDT.
TRACER RUN NO. 7;
JULY 29, 1957
LEGEND:
LIMIT OF EXPECTED DISPERSION
WIND AT TV TOWER (STATION 11)
SURFACE WIND (STATIONS 1 & 7)
LENGTH OF ARROW INDICATES MILES OF WIND MOVEMENTS IN 30 MINUTES.
- TRACER RELEASE POINT IN RUBBERTOWN
- TRACER SAMPLING STATION
- TV TOWER (STATION 11)
36 - NUMBERS AT SAMPLING STATIONS INDICATE NUMBER OF TRACER PARTICLES FOUND ON FILTER.
X - MEANS DATA MISSING
0 1 2
SCALE IN MILES

Figure 3-14. RESULTS OF SEVEN TRACER RUNS - JULY, 1957

necessary to use a multiple component representation of flow.

The width of the sector over which the tracer was expected to disperse (indicated by dashed lines on figures) was calculated from the ranges of wind direction recorded. The method of calculation was to assume that the azimuth difference from the mean wind direction to the dispersion limits was two-fifths the azimuth difference between mean wind direction and the fifth highest veering (or backing) direction for an hourly record obtained at stations 1, 7, and/or at the TV tower (station 11). These calculated azimuth differences were then added to (or subtracted from) the azimuth direction of the mean wind. When the tracer material was released at the low level (40 feet above ground-runs 1 and 2) the mean wind direction was taken to be the average of the surface wind directions recorded at stations 1 and 7. In runs 4 and 6, the mean wind direction was calculated to be three-fourths the surface wind plus one-fourth the TV tower wind. In runs 3, 5, and 7, mean wind direction was computed from combinations of surface and TV tower data.

Individual Tracer Runs

Tracer run 1. The air was convectively unstable due to intense ground heating by bright sunshine. Strong horizontal and vertical diffusion rapidly dispersed the relatively small amount of tracer material released, giving the low counts observed.

Tracer run 2. The air was changing from stable to convectively unstable as a deck of middle clouds dissipated, allowing more solar heat to reach the ground. The main component of turbulence was probably mechanically induced eddies caused by relatively strong winds. The wind direction traces indicated that only short period (less than one minute) turbulence was present.

Tracer run 3. This run was made during a period of air flow of a type rarely observed. There was a quasi-stagnant air mass over the region, with only a light southerly flow over the Louisville area during the afternoon hours preceding the run. Shortly before release time, wind direction at the TV tower shifted almost 180 degrees, to come from the north-northwest; this flow was reflected by a somewhat delayed and more gradual shift of the wind at station 1, to come from the west-northwest. Evidently, the northwesterly flow was over-running air flow from the south and southwest at the surface, and gradually replacing the surface flow. The wind directions at station 1 and at the TV tower showed much larger deviations towards a southerly than a northerly direction during the period of the tracer run, and the same skewed distribution of wind direction deviations at station 3 also occurred after the wind shift at that location.

Tracer run 4. The run was made a a time when a stable air layer was slowly developing at the surface. The sky was partially covered by a deck of middle clouds, which would somewhat inhibit outgoing radiation from the ground surface. Convective turbulence had died off by the time the run was started. Because of the developing stable layer at the surface, downward diffusion of the tracer was reduced and the maximum ground level counts probably occurred beyond the outermost sampling arc.

Tracer run 5. Broken to overcast middle clouds delayed the morning breakup of the stable surface layer until the time of the run. Air flow during the previous night had been from the northeast. The northeast flow had ceased, and by the time of the run, the upper winds had already reversed, to come from a southwesterly direction. The surface flow was non-existent at the start of the run, with only random small motions. The surface flow first showed a definable direction about 40 minutes after the start of the run, coming from a southerly direction. Half an hour later, the complete breakup of the stable layer occurred, with the surface winds essentially the same as the upper wind. The final breakup would probably remove air that had been within a few hundred feet of the ground, so that the dispersion pattern observed is most likely the result of the earlier process, in which the tracer material was carried slowly by a southwesterly flow, with portions of the tracer-laden air being carried to ground level by convective eddies and subsequently drifting slowly northward at ground level, gradually diffusing. The highest counts should, therefore, be expected on the right side (looking downwind) of the dispersion pattern. This run produced the highest total of tracer particles collected of any run, probably because the mean motion of the air was smaller in this run than in any other, so that the tracer remained over the sampling network for a greater length of time.

Tracer run 6. A stable surface layer was just starting to develop, with convective eddies gradually dying out, at the time of the start of the run. Conditions during the run were similar to those during run 4, but since this run represents an earlier state in the transition from day to night-time conditions, more rapid diffusion both horizontally and vertically occurred; also, there was slight meandering indicated by wind direction records. Somewhat higher counts were observed during this run than during run 4, because of the greater diffusion rate near the ground. The dispersion pattern was near the southern edge of the sampling network, however, precluding observation of a significant portion of the expected pattern.

Tracer run 7. This run was made during the morning breakup of the stable surface layer; conditions were similar to those during run 5. The flow during the preceding night had been from a southerly direction at the surface and aloft. At the start of this run, the surface wind speeds had decreased from those observed before sunrise, and were very light, with the directions quite variable, but showing mostly a flow from the east or south. Within half an hour after the start of the run, the surface flow settled down to a consistent southerly direction, with speeds gradually increasing to 4-5 mph. A more gradual transition to daytime flow occurred, rather than the abrupt final breakup of the stable layer that occurred during run 5. The greater consistency of wind direction with height resulted in a narrower dispersion pattern of the tracer at ground level. The highest counts probably occurred on the right side of the pattern. Unfortunately, only a portion of the expected pattern was over the sampling network, precluding complete observation.

Summary of Findings from Tracer Studies

Tracer particles released in Rubbertown were always recovered at several sampling stations in western Louisville. The dominant effect of meteorological conditions on ground level concentration was demonstrated in that the number of tracer particles found in samples was many times greater for some runs than for others with the same amount of tracer released from the same point. Since the tracer particles diffuse in approximately the same manner as gases or fine particles, such materials released from industrial plants in Rubbertown will be dispersed over western Louisville in patterns similar to those demonstrated by the tracer studies.

MEASUREMENTS OF SUSPENDED PARTICULATE MATTER

Total Weight of Suspended Particulate Matter

High volume air samplers were used to collect suspended particulate matter on filters at six stations (Numbers 1 through 6; see Figure 2-1). Three samples were collected each day at each station representing the time periods 2400 to 0800; 0800 to 1600; and 1600 to 2400 CST: designated periods one, two, and three respectively. All samples were analyzed for total solids and selected sampled were further analyzed for calcium, chlorides, organics, sulfates, and nitrates. All values are expressed as $\mu g/m^3$ of air sampled.

The mean annual total particulate concentration at the four western Louisville air quality stations (Numbers 1, 4, 5 and 6) was 119 $\mu g/m^3$ for the 12 month period April, 1956 through March 1957 (Table 3-16). These 12 months were used in order to give proper representation to the four seasons of the year. Concentrations were lowest at station 4, with a mean of 98 (Figure 3-15); stations 1, 5 and 6 averaged approximately 25 percent more than this. The location of station 4 in a park with few sources close by to the east and only the river to the west, is one reason for the lower values at this station.

The January-May mean total particulate concentration for all stations combined was considerably lower in 1957 than in 1956. It is not possible to determine how much of this difference is due to variation in meteorological conditions and how much is due to difference in source strength. It is known that a decrease in particulate matter emitted from Rubbertown sources occurred from 1956 to 1957, notably that from a dusty pilot plant at Rubbertown industry number 8.

Seasonal variation was not uniform among the six stations. The ratio of total particulate concentrations in January 1957 to those in July 1956 varied from 1.00 at station 2 to 1.32 at station 4 (Table 3-16). It is clear that the seasonal variation is not pronounced. The principal sources of particulate matter having pronounced seasonal variation are those used for space heating. However, the weight of coarse particulate matter ($> 1 \mu$) emitted from such sources is small compared to the total coarse particulate matter emitted from

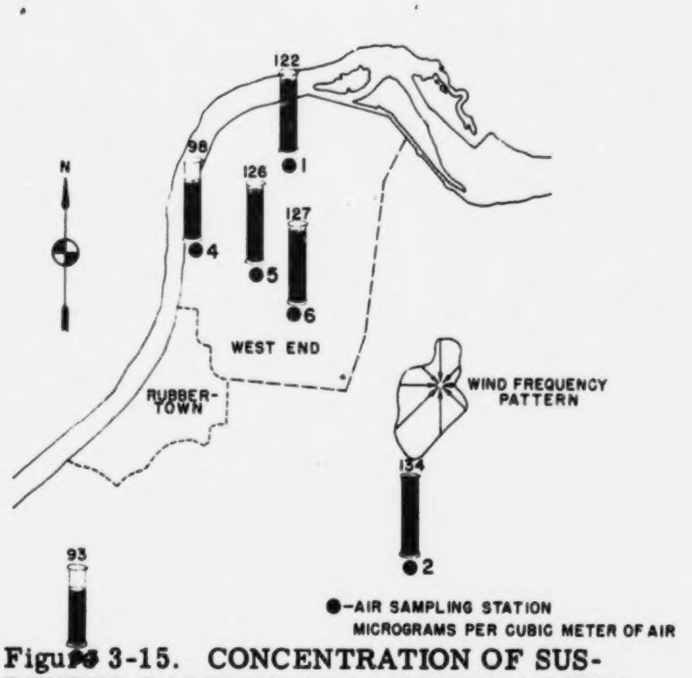


Figure 3-15. CONCENTRATION OF SUSPENDED PARTICULATE MATTER AT NETWORK STATIONS (SAMPLES COLLECTED WITH HIGH VOLUME FILTER)

all types of sources (Figures 3-8 and 3-9). The weight of fine particulate matter ($< 1\mu$) emitted by sources used for space heating is a major part of the total fine particulate matter emitted (Figures 3-8 and 3-9). Coarse particles in the ambient atmosphere have a greater effect on measurements of particulate matter based on weight of material collected than do fine particles, while fine particles in the ambient atmosphere have a greater effect on measurements of particulate matter based on reduction of light transmission (soiling) than do coarse particles. This would account for the lack of a pronounced seasonal variation in weight of particulate matter collected in samples and the pronounced seasonal variation found in "soiling" samples, described later herein. It should be recognized, however, that other factors such as meteorological conditions for dispersion of pollution also influence seasonal variation in particulate matter in the air.

Total particulate concentrations for the three sampling periods of the day in the rural area (station 3) were very nearly equal (Table 3-16). Concentrations were similar for only periods one and two at the western Louisville stations (Numbers 1, 4, 5, and 6). The third period (1600 to 2400 CST) averaged higher for every month of the year (Figure 3-16), especially during the months of May through November, with the greatest difference, 75 percent greater, during October. The reasons that period three concentrations were higher than periods one and two include the following: (a) greater frequencies of nocturnal inversions and consequent increased air pollutant concentrations during the early evening hours of the summer and fall seasons; (b) home heating during only the morning and early evening hours of the spring and fall (pollutants due to morning heating would be split between the 2400 to 0800 and the 0800 to 1600 periods, whereas pollutants generated during evening heating would be in only period three from 1600 to 2400); (c) generation of pollutants due to leaf burning during evening hours in the fall; and (d) possible tendency for western Louisville and Rubbertown industries to clean furnaces and boilers and to service air cleaning units during the 1600 to 2400 shift. These operations often result in release of an unusually large amount of particulate matter.

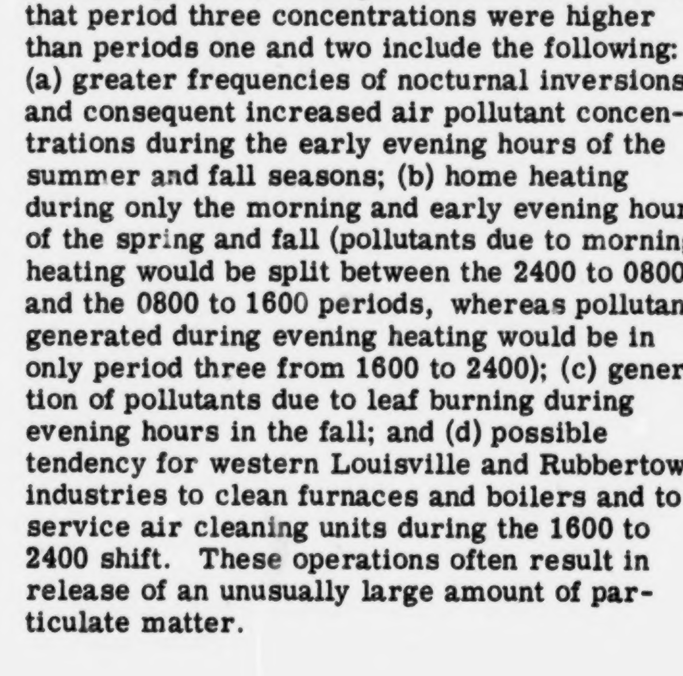


Figure 3-16. SUSPENDED PARTICULATE CONCENTRATION BY SAMPLING PERIOD, JAN. 1956 - MAY 1957

The difference in total air-borne particulate concentration upwind and downwind of Rubbertown was determined in order to evaluate the effect of pollution emissions from Rubbertown. A 32 percent increase in concentration occurred when air passed southwesterly from western Louisville, over Rubbertown, and on to station 3 (Figure 3-17). An 84 percent increase occurred when the air passed northeasterly over station 3, Rubbertown, and on to western Louisville (Figure 3-18).

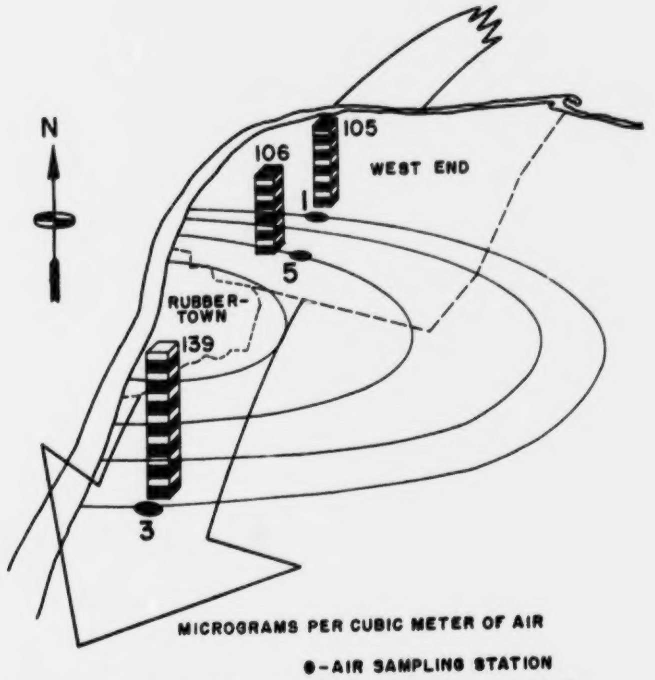


Figure 3-17. CONCENTRATION OF SUSPENDED PARTICULATE MATTER WITH NORTHEASTERLY WINDS

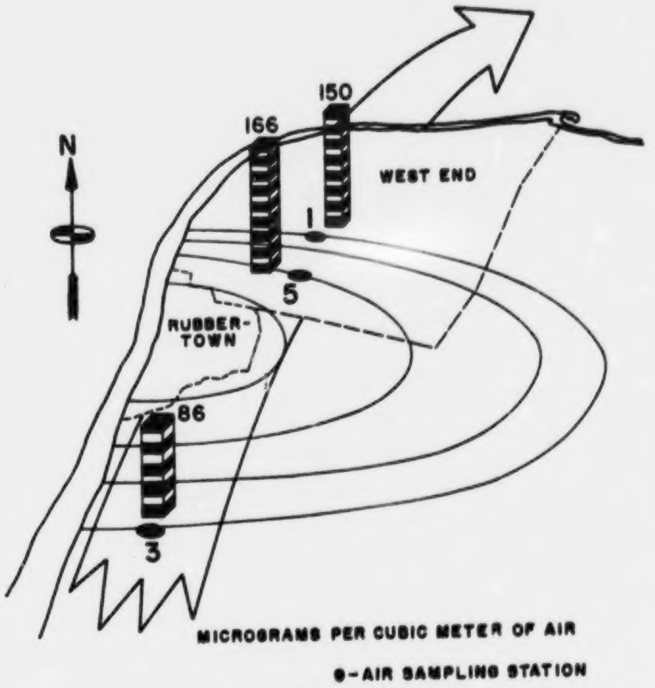


Figure 3-18. CONCENTRATION OF SUSPENDED PARTICULATE MATTER WITH SOUTHWESTERLY WINDS

Particulate samples were grouped on the basis of whether, during the sampling period, the wind was blowing from Rubbertown toward the sampling site (a Rubbertown wind); the wind was not blowing from Rubbertown to the sampling station (a non-Rubbertown wind); or the wind was variable in direction (a mixed wind). The procedure for so grouping winds is described in the meteorological part of the chapter titled "Study Activities and Methods." Total particulate concentrations in western Louisville (stations 1, 4, 5, 6) were found to be 31 percent greater when the wind blew from Rubbertown than when it did not (Table 3-17, Figure 3-19). The greatest difference occurred during period one when concentrations with Rubbertown winds were 49 percent greater than with non-Rubbertown winds, and the least difference, 19 percent, occurred during period two. This difference between periods is probably due to some combination of meteorological patterns and pollution emission rates.

Western Louisville stations 1, 4, and 5 showed 32-39 percent greater concentrations when the wind blew from Rubbertown than when it did not. Station 6, located towards the eastern edge of western Louisville, showed only ten percent greater concentrations with Rubbertown winds as compared to concentrations with non-Rubbertown winds, demonstrating the influence of air pollution sources to the east of this station. Station 2, located 3.5 miles southeast of Rubbertown, showed lower concentrations with Rubbertown winds than with non-Rubbertown winds, demonstrating the greater importance of sources other than Rubbertown to pollution at this station. The greatest difference due to wind direction occurred at station 3; with winds blowing from Rubbertown (and western Louisville) concentrations were 75 percent higher than with winds blowing from the rural areas to the southwest.

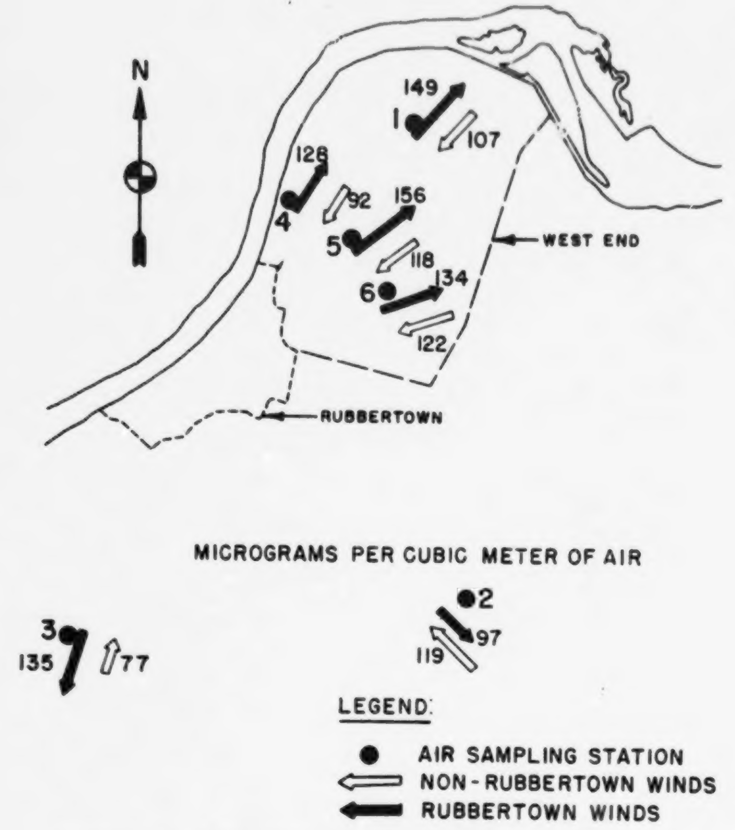

N
149
1
107
128
4
92
156
5
118
6
134
122
WEST END
RUBBERTOWN
MICROGRAMS PER CUBIC METER OF AIR
3
135
77
2
97
119
LEGEND:
● AIR SAMPLING STATION
NON-RUBBERTOWN WINDS
RUBBERTOWN WINDS

Figure 3-19. VARIATION OF SUSPENDED PARTICULATE CONCENTRATIONS WITH WIND DIRECTION

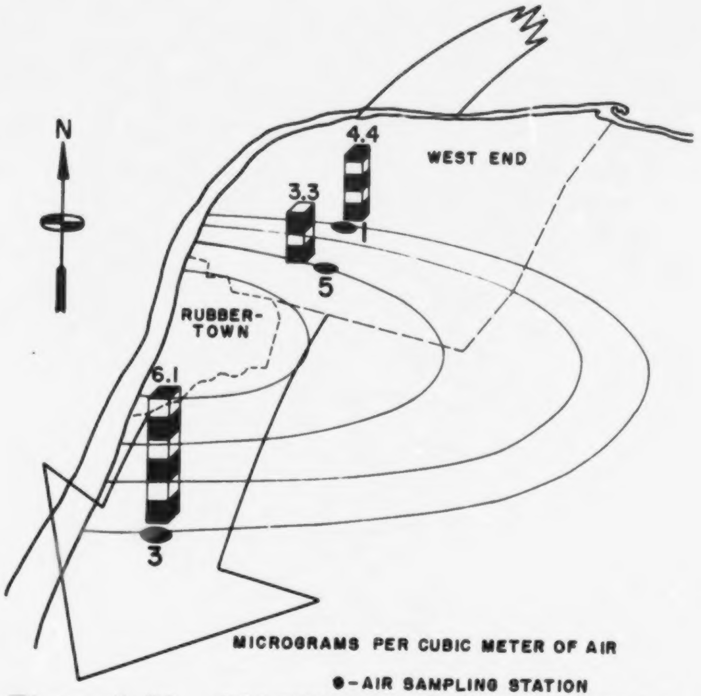

N
4.4
WEST END
3.3
1
5
RUBBER-TOWN
6.1
3
MICROGRAMS PER CUBIC METER OF AIR
●-AIR SAMPLING STATION

Figure 3-20. CALCIUM IN SUSPENDED PARTICULATE MATTER WITH NORTHEASTERLY WINDS

There was a marked seasonal variation in the ratio between particulate pollution loadings with Rubbertown and non-Rubbertown winds, ranging from 1.05 in the fall to 1.53 in the summer at western Louisville stations 1, 4, 5, 6 (calculated from Table 3-17). No explanation of the variation was evident.

Calcium. The source inventory indicates that large quantities of calcium-bearing particulates are emitted from Rubbertown industry number 8 (Table 3-10). The effect of this source was demonstrated by the change in airborne calcium concentrations which occurred as wind passed over Rubbertown. A 60 percent increase in concentration occurred when the wind passed from western Louisville over Rubbertown and on to station 3 (Figure 3-20), and an 100 percent increase in calcium concentration occurred when the wind passed in the opposite direction, from station 3, over Rubbertown and to western Louisville (Figure 3-21).

Western Louisville calcium particulate concentrations were 2.7 times greater with

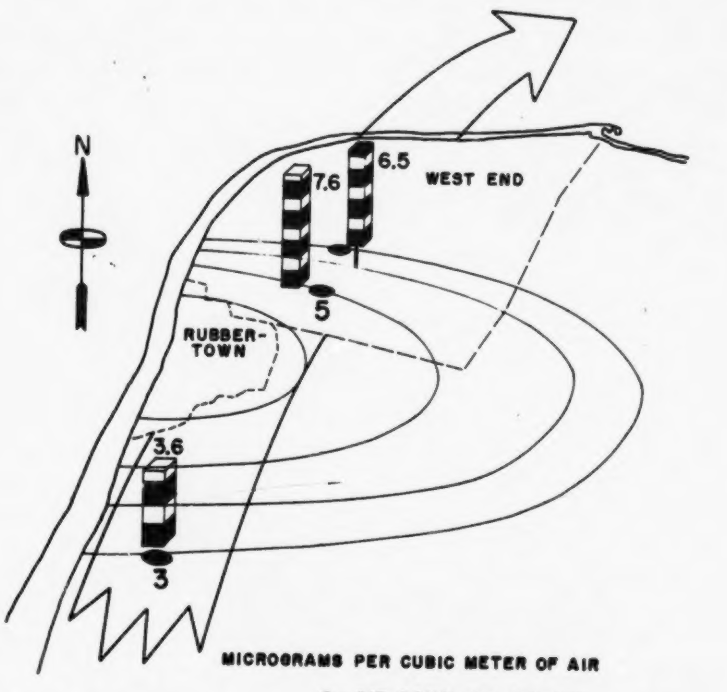

N
6.5
7.6
WEST END
1
5
RUBBER-TOWN
3.6
3
MICROGRAMS PER CUBIC METER OF AIR
●-AIR SAMPLING STATION

Figure 3-21. CALCIUM IN SUSPENDED PARTICULATE MATTER WITH SOUTHWESTERLY WINDS

Rubbertown winds than with non-Rubbertown winds, the ratio varying from 1.9 for station 6 to 3.2 for station 1 (Table 3-18 and Figure 3-22).

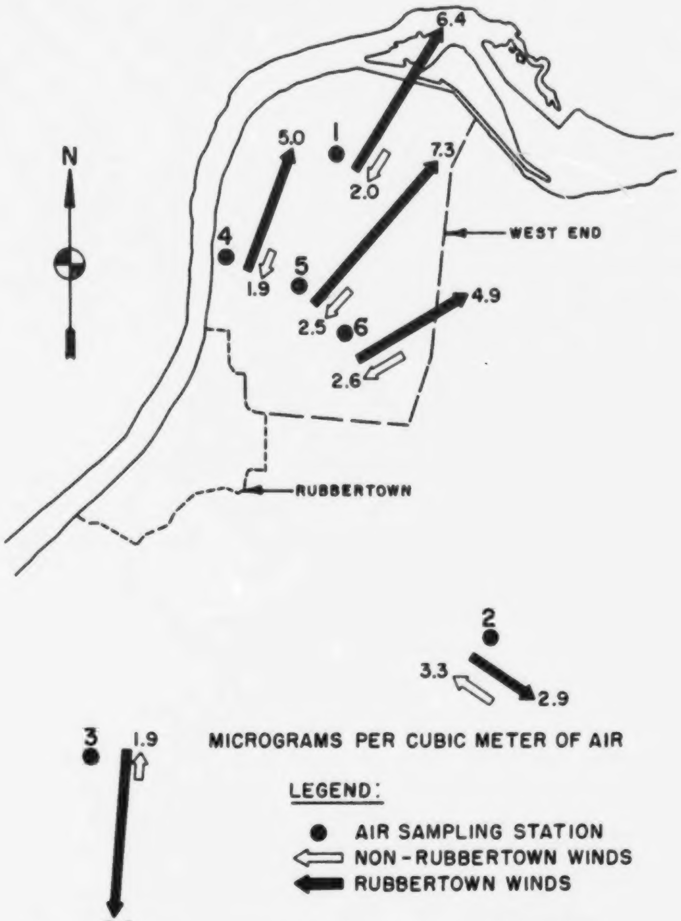

N
6.4
5.0
1
2.0
7.3
WEST END
4
1.9
5
2.5
6
4.9
2.6
RUBBERTOWN
2
3.3
2.9
3
1.9
6.4
MICROGRAMS PER CUBIC METER OF AIR
LEGEND:
● AIR SAMPLING STATION
⇦ NON-RUBBERTOWN WINDS
⬅ RUBBERTOWN WINDS

Figure 3-22. VARIATION OF CALCIUM CONCENTRATION IN SUSPENDED PARTICULATE MATTER WITH WIND DIRECTION

Chlorides. The mean chloride concentration in particulate matter collected at western Louisville stations was 2.5 times greater with winds blowing from Rubbertown than with winds blowing from other directions (Table 3-19, Figure 3-23). For individual western Louisville stations, the ratio ranged from 1.6 at station 6 to 4.0 for station 4. The higher chloride concentrations with Rubbertown winds is in keeping with the source study results which indicate that significant uantities of chlorine-containing compounds re emitted from sources in Rubbertown Figure 3-7 to 3-9).

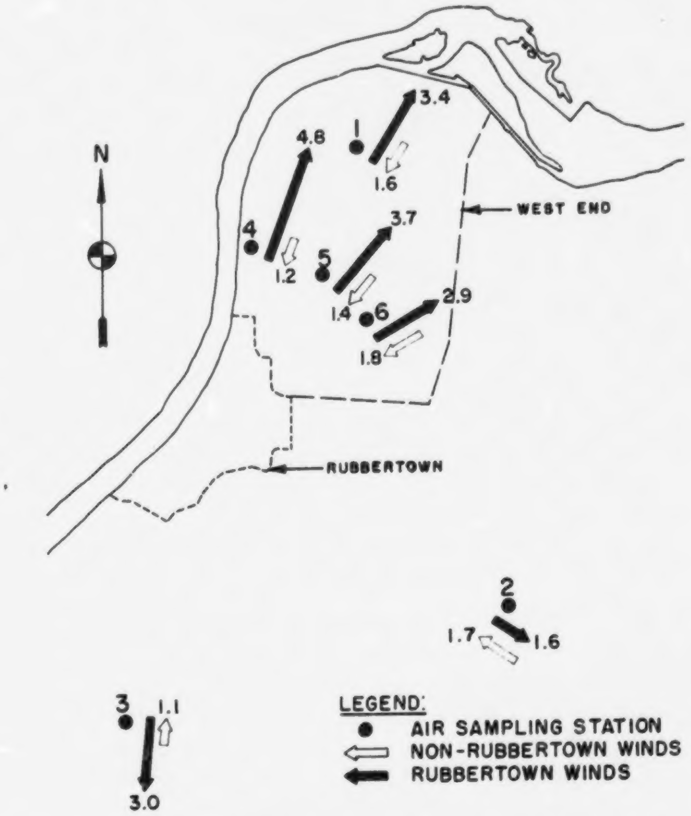

3.4
4.8
1
1.6
N
WEST END
3.7
4
5
1.2
2.9
1.4
6
1.8
RUBBERTOWN
2
1.7
1.6
3
1.1
3.0
LEGEND:
● AIR SAMPLING STATION
⇦ NON-RUBBERTOWN WINDS
⬅ RUBBERTOWN WINDS

Figure 3-23. VARIATION OF CHLORIDE CONCENTRATION IN SUSPENDED PARTICULATE MATTER WITH WIND DIRECTION

At western Louisville stations, fall, winter, and spring mean concentrations were relatively uniform, ranging from 1.8 to 2.5 $\mu g/m^3$ of chloride. The absence of a pronounced peak during the winter space heating season tends to support source emission data which indicate that space heating is responsible for a small part of the total chloride emissions to the atmosphere (Figure 3-7 to 3-9).

Organics. Benzine soluble organics in suspended particulate matter at all air sampling stations varied markedly by season, being approximately three times higher in November 1956 than in July 1956 (Table 3-20 and Figure 3-24). The rate of emission of particulates from fuel combustion at industrial plants and from use of coal at domestic and commercial establishments showed a similar seasonal trend (Figure 3-25), as did total particulate emissions from all fuel combustion (Figure 3-26). It is believed that domestic, commercial, and industrial combustion processes are the prime sources of organic particulates.

Use of fuels in transportation and other sources are of lesser magnitude.

A pronounced diurnal variation in organic particulate concentrations were observed at all stations except the rural station (Number 3) where diurnal variation was relatively small. The lowest average concentrations occurred during period two (0800 to 1600) at all stations. The highest average concentrations occurred during period three at all stations except station 3. Generally, the pattern occurred throughout the year (Table 3-20). Factors contributing to this pattern are the following: (a) Meteorological conditions for dispersion of pollutants are best during period two; (b) The evening peak of automobile traffic occurs largely within period three while the morning peak is divided between periods one and two; (c) During the space heating season emissions from domestic space heating units are greatest in period three; (d) Leaf and refuse burning are more prevalent in period three than in the other two periods; (e) During the fall and spring, space heating may be necessary only during early morning and evening hours. Pollutant emissions due to morning heating would be split between periods one and two whereas pollutants released during evening heating would be in only period three.

Western Louisville organic particulate concentrations with Rubbertown winds were 15 percent lower than with non-Rubbertown winds (Table 3-21). The lowest ratio of concentrations with Rubbertown winds to concentrations with non-Rubbertown winds was 0.55 at station 6; the remaining western Louisville concentration ratios varied from 0.65 for station 2 to 1.86 for station 3. These ratios indicate that both Rubbertown and Western Louisville are important sources of organic particulates. When particulates due to domestic and commercial coal combustion in western Louisville are added to that from Rubbertown, in the case of non-Rubbertown winds, station 3 shows large organic loadings for a rural station.

Sulfates. Particulates containing sulfates occur in various dusts of natural origin and are also produced to some degree by the interaction between particulates and sulfur gases emanating from combustion processes.

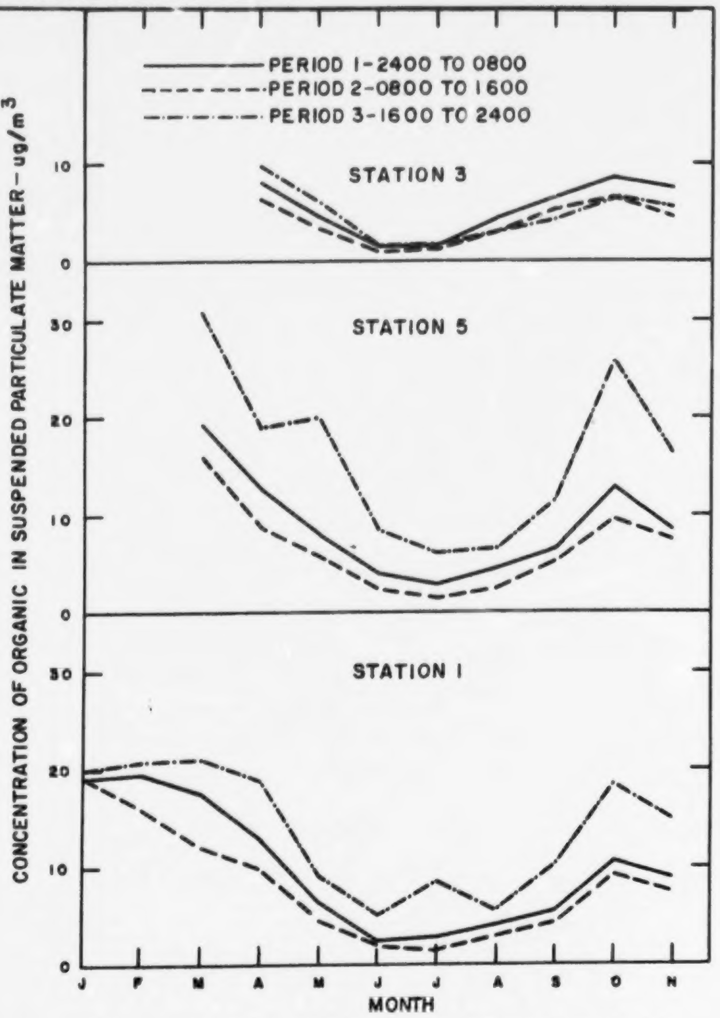


Figure 3-24. ORGANICS IN SUSPENDED PARTICULATE MATTER; THREE STATIONS - 1956 (SAMPLES COLLECTED WITH HIGH VOLUME AIR SAMPLER)

The ratio of sulfate concentrations with Rubbertown and non-Rubbertown winds at stations 1, 4, and 5 were near unity (Table 3-22), indicating that Rubbertown is not a dominant source of sulfate particulates. A ratio of 2.5 at station 3 indicates stronger sources of sulfate particulates in the Rubbertown-western Louisville areas as compared to other surrounding areas. The ratio of 0.5 at station 6 indicates that sources in the direction toward Rubbertown are of lesser magnitude than sources lying in other directions from station 6.

Nitrates. Nitrate concentrations in suspended particulate matter (Table 3-23) did not indicate that Rubbertown was a dominant nitrate source. This is in agreement with the source study, which indicates no large sources of nitrates in Rubbertown. At stations 4, 5, and 6 in western Louisville, nitrate concentrations were approximately twice as high with winds from the north and east as with winds from Rubbertown. At

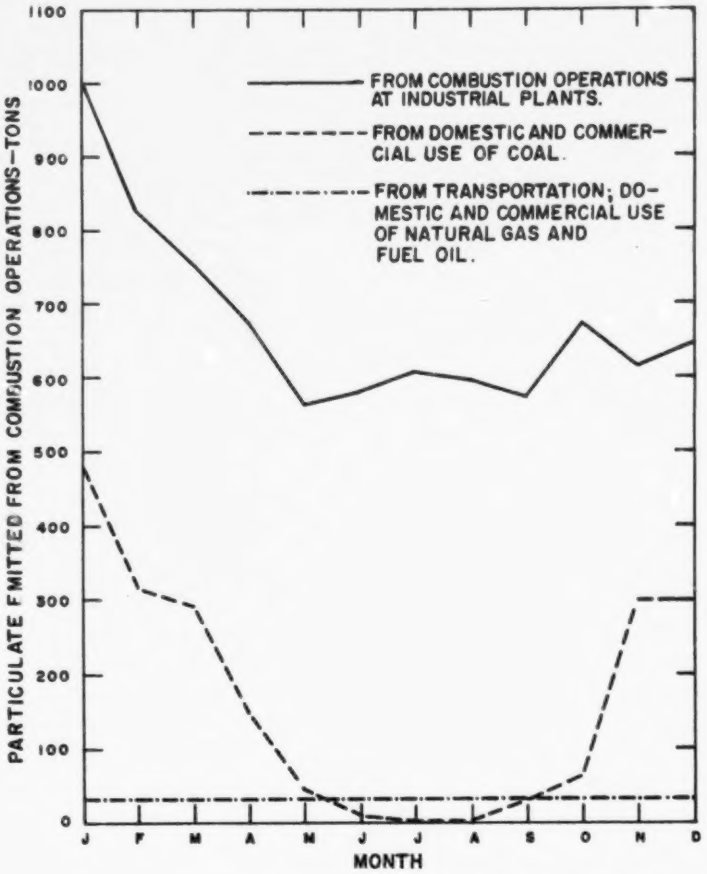


Figure 3-25. MONTHLY VARIATION IN EMISSION OF PARTICULATES FROM COMBUSTION OF FUELS; 1956

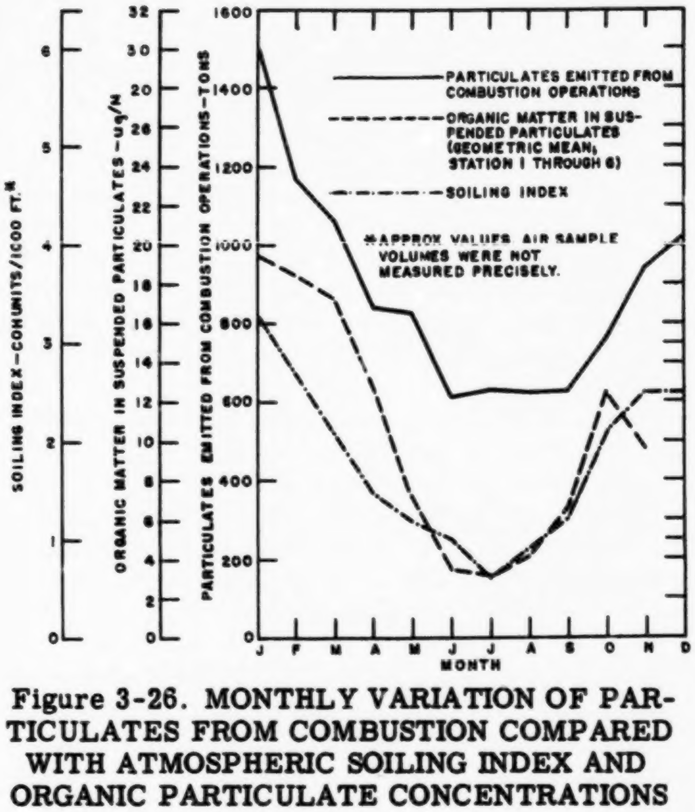


Figure 3-26. MONTHLY VARIATION OF PARTICULATES FROM COMBUSTION COMPARED WITH ATMOSPHERIC SOILING INDEX AND ORGANIC PARTICULATE CONCENTRATIONS

station 3, concentrations were 2.5 times greater when winds blew from Rubbertown and western Louisville than when non-Rubbertown winds prevailed, probably indicating the effect of general urban pollution reaching the station.

Suspended Particulate Matter During Prolonged Atmospheric Stagnation

A prolonged period of atmospheric stagnation occurred over much of the eastern United States during the period October 15-19, 1956. During this time, mean concentration of total suspended particulate matter at western Louisville stations (Table 3-24) was 44 percent greater than the mean for the remainder of October. The highest concentrations during the stagnation period occurred during sampling period three, with a mean concentration of 260 $\mu g/m^3$ for the five days, 35 percent greater than the mean concentration for all three daily sampling periods.

The ratios of concentrations during the October 15-19 period to concentrations during the remainder of October for components of particulate matter ranged from 1.25 for chloride to 1.95 for calcium. During the stagnation period, the ratio of concentrations during period three to concentrations during all periods for organic material was 1.55. The same ratio was near unity for calcium, chloride, and sulfate (Table 3-24).

Optical Density (Soiling)

Two hourly samples of suspended particulate matter were collected continuously using AISI (American Iron and Steel Institute) type automatic strip filter paper samplers. Particulates collected were largely less than five microns in diameter. Optical density measurements were used to evaluate the amount of particulates collected. Samplers were operated at six aerometric network stations. Results for all stations were similar in nature. Only data from station 5 (Figure 2-1) are presented to illustrate results obtained.

A pronounced seasonal variation is evident in optical density of suspended particulate matter with mid-winter values being about four times greater than mid-summer values (Figure 3-26 and Table 3-25). The pattern of monthly variation in optical density is very similar to the pattern of monthly variation of emission of particulates from combustion operations (Figure 3-26) and monthly variation in domestic and commercial space heating (Figure 3-25). It is concluded that the major source of particulate matter causing high values of optical density in samples (and therefore indicating a probable cause for decreased visibility) are space heating units. Industrial combustion operations, industrial processes, and motor vehicles also contribute but to a lesser degree. It is recognized that seasonal variation in meteorological factors which influence dispersion also influence seasonal variation in optical density values obtained.

Optical density values obtained when Rubbertown winds prevailed were lower than values with non-Rubbertown winds during 9 of the 13 months of sampling, but average values for the two wind patterns were nearly the same (Table 3-25). Values during periods of mixed winds were higher than with Rubbertown or non-Rubbertown winds. These data indicate that Rubbertown is not the predominant source of particulate matter causing high values of optical density in samples, in the long-time average situation. However, situations were noted in which pollution emissions from Rubbertown were an important factor in causing decreased visibility in West End Louisville.

Summary of Findings from Measurements of Suspended Particulate Matter

On the average total weight of suspended particulate matter in the air over western Louisville amounts to about 119 μg/m,^{3} a loading typical of cities the size of Louisville. However, occasional higher concentrations do occur. No pronounced seasonal variation in total weight of suspended particulate matter was noted, indicating that space heating was not a predominant factor influencing this measure of pollution levels. Diurnal variation in total particulate pollution was marked, with considerably higher values occurring during the period 1600-2400 hours, because of a combination of pollution source characteristics and meteorological conditions for dispersion of pollutants. Total particulate loadings were 10 to 80 percent higher with winds carrying pollutants from Rubbertown to sampling stations than when winds were not carrying pollutants from Rubbertown, indicating that emissions in Rubbertown cause a significant increase in total particulate pollution in neighboring areas.

Calcium in collected suspended particulate matter was 1.9 to 3.2 times greater at sampling stations when air flow was such that pollutants arising in Rubbertown would reach the stations than during other wind regimes. These data demonstrated the strong influence of sources of calcium bearing particulate pollutants in Rubbertown (especially industry number 8) on pollution levels in surrounding areas due to calcium bearing particulate matter.

Chlorides in collected suspended particulate matter were present in 1.6 to 4.0 times greater amounts at West End sampling stations when air flow was such that pollutants, arising in Rubbertown, would reach the station than during other wind regimes, demonstrating the influence of sources of chloride bearing particulates in Rubbertown on pollution levels in surrounding areas due to chloride bearing particulate matter. The absence of relatively high concentrations during the space heating season indicated that use of fuels for space heating is not a major source of chloride bearing particulate matter. Concentrations of benzene soluble organics in suspended particulate matter are about three times higher during the winter than during the summer. This fact and other data lead to the conclusion that use of fuels for space heating is the prime source of this class of pollutants. Lesser sources are use of fuels by industry for non-space heating purposes and use of fuels in transporation activities. Organic particulate pollution levels were found to have a pronounced diurnal variation, with higher concentrations occurring between 1600 and 2400 hours and lower concentrations occurring between 0800 and 1600 hours. The pattern of variation is due to the influence of pollutant emission rates and meteorological conditions affecting dispersion of pollutants.

Rubbertown pollution sources are not dominant in affecting levels of sulfates and nitrates in suspended particulate matter in West End Louisville.

Optical density (soiling) measurements of suspended particulate matter indicate that space heating units are the predominant source of particulates causing higher values of optical density in samples. It is probable that these pollution sources are the major man-made cause of decreased visibility in the atmosphere in the long time average situation. Industrial processes, industrial use of fuel for purposes other than space heating, and motor vehicles also contribute but to a lesser degree.

MEASUREMENTS OF GASEOUS POLLUTANTS

Aldehydes; Hydrogen Chloride; Nitrogen Oxides; Ozone; Oxidants

Gas samples were collected from 0800 to 0900 and 2000 to 2100 CST during the period June 18 - August 16, 1957, at gas sampling stations C and D (Figure 2-1). Aldehydes, hydrogen chloride, nitrogen oxides, ozone, and total oxidants were measured. Some of these pollutants were expected from specific sources and others were expected to reflect generalized pollution. The source study indicates major emissions of nitrogen oxides from industrial plants number 3, 6, and 7 and a major emission of hydrogen chloride from industry number 3. Aldehydes are emitted by several industries as well as from motor vehicles and domestic heating plants. Ozone and total oxidants were not expected as emissions from particular sources but rather are expected as the result of possible atmospheric photochemical reactions between nitrogen oxides and hydrocarbons in the presence of sunlight.

Aldehydes were the only pollutant for which concentrations frequently exceed the irritation threshold during this limited sampling period; maximum concentrations exceed the eye irritation threshold of 250 ppb by factors of 2.6 to 4.2 (Table 3-26). The threshold was exceeded on three-fourths and one-third of the days on which samples were collected at station C and at station D respectively. The maximum measured hydrogen chloride concentration approximated one-half of that allowed for an industrial working atmosphere. The maximum ozone concentration reached 70 percent of the eye irritation threshold and maximum recommended industrial work-room concentrations.

Aldehyde concentrations were greatest (median about 110 ppb) when winds blew from either of the power stations (Plants 6 and 7) towards station D. Median values with other wind directions were 5-50 ppb. At station C, aldehyde concentrations with winds from the power station (and Rubbertown) had a median of about 200 ppb. However, with winds from the downtown Louisville area (northeast) median values were also high (120 ppb). With winds from other directions, median values were below 20 ppb. The high concentrations with northeast winds may be due in part to aldehydes emanating from a burning dump located to the north across the Ohio River and multiple sources such as motor vehicles and other fuel burning units. The data indicate that burning of coal, as well as other fuels, results in emission of aldehydes, although data were not available upon which to base estimates of emissions in source studies described earlier herein.

Aldehyde measurements were also made at stations E and F for several weeks during June, July, and August 1957, with 12 two-hour samples being taken daily using an automatic sequential sampler. It was found that the eye irritation threshold (250 ppb) was exceeded on about one third of the days on which samples were collected. Winds from Rubbertown toward station C brought effluents from Rubbertown sources to station C more frequently than to stations D, E, and F and this probably contributed to the higher frequency of values above the eye irritation threshold at station C. Aldehydes discharged in Rubbertown may have passed overhead at station E on occasions.

Sulfur Dioxide

Sulfur dioxide concentrations were measured continuously at stations A and B using Thomas Autometers. Data from the two stations were similar. Only data from station B are given here. A plot of monthly mean values of daily maximum sulfur dioxide concentrations (Figure 3-27) shows that winter time values were approximately 50 percent greater than summertime values, reflecting the fact that more sulfur dioxide is released to the atmosphere during the winter heating season than during the summer.

A marked diurnal variation was observed, with the lowest concentrations occurring between 2400 and 0600 CST; the highest from 0600 to 1200; and concentrations between these two from 1200 to 2400. The low 2400 to 0600 values are due primarily to two

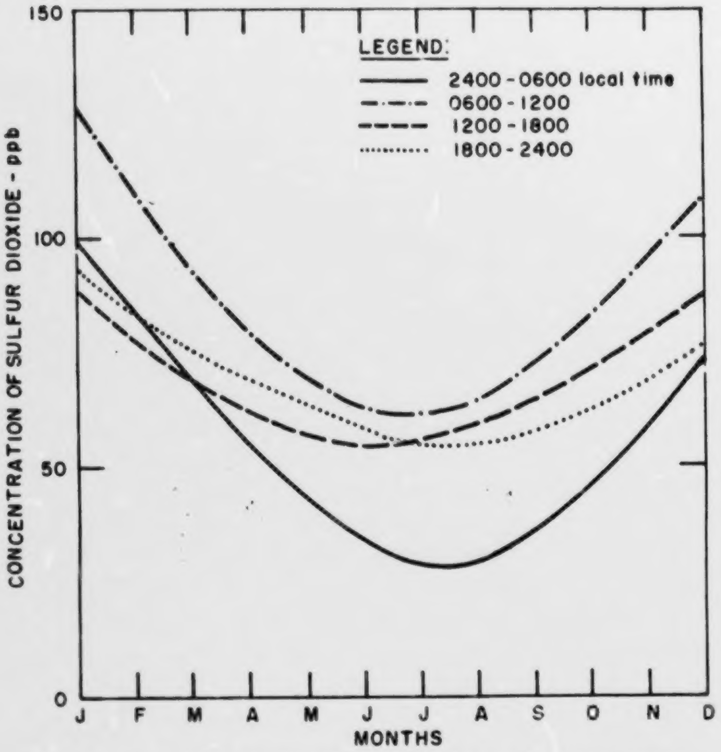


Figure 3-27. MONTHLY MEAN VALUES OF DAILY MAXIMUM SULFUR DIOXIDE CONCENTRATION (STATION B; 1956; THOMAS AUTOMETER)

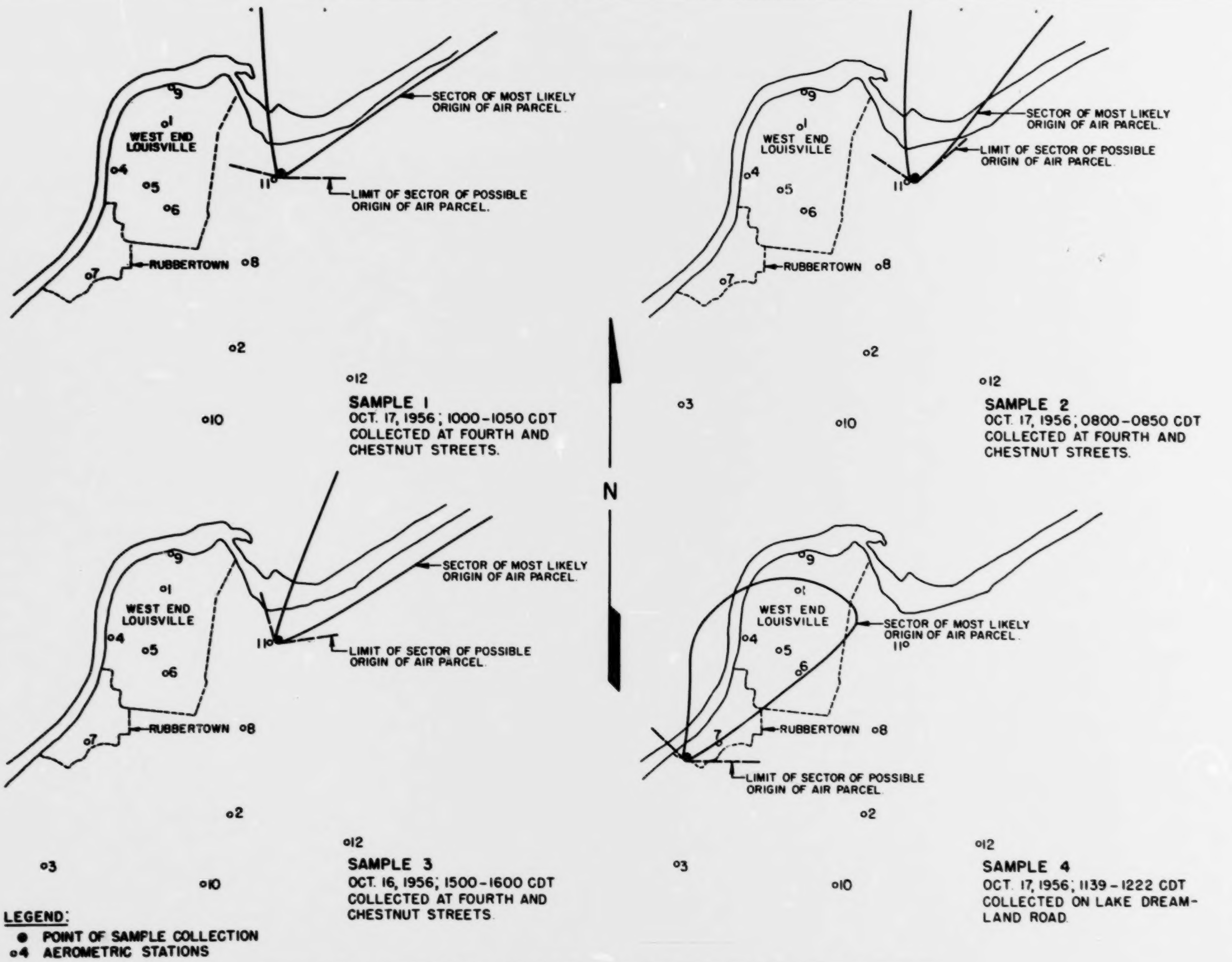
factors; less coal combustion during the night-time hours and less mixing of plumes from tall stacks (especially power station stacks) with the lower levels of the atmosphere during this period when the atmosphere is relatively stable. Conversely, high concentrations from 0600 to 1200 are due to increased fuel combustion by homes and industries and greater mixing of sulfur dioxide discharges with air at ground level, including transport to the ground of sulfur dioxide discharged during the night, at high elevations, as nocturnal inversions are being dissipated shortly after sunrise.

The sulfur dioxide taste threshold of 300 ppb was exceeded at station B on one-third of the days in 1956 (Table 3-27). The threshold was exceeded on approximately half of the days in winter and one-fifth of the days in summer. The hours during which maximum sulfur dioxide values exceeded the threshold was approximately five percent in mid winter and one and one-half to two percent in summer. The odor threshold concentration of sulfur dioxide, 3000 ppb, was exceeded on one day in the winter and one day in the summer (Table 3-27).

Non-Selective Gas Samples

Non-selective gas samples were collected during the October 15-19, 1956 period of atmospheric stagnation and at other times when presence of odors in the air was marked. Samples were collected using the freezeout technique and large grab sampling containers. Data obtained by mass spectrometric analysis of material collected are given in Table 3-28. Date, time, place, and means of sampling are shown on Figures 3-28 and 3-29. The figures also show an estimate of areas from which air sampled had come, based on meteorological data from network stations. Back trajectories of air arriving at each sampling location during the sampling period were drawn, and a trajectory width was computed from the recorded ranges of wind direction. In the figures, two trajectory widths are indicated. The solid heavy line encloses the sector of most likely origin of air samples. This sector was obtained by multiplying the angle between hourly prevailing wind direction and the veering and backing maxima of direction by a factor of 0.4, and adding or subtracting these angles from the prevailing hourly wind direction, with adjustments as necessary for trajectory curvature. The dashed heavy lines are the directions of the veering and backing maxima, and indicate the limits of direction from which any air parcel might have come. The most likely sector area is extended upwind for a distance corresponding to the wind speed multiplied by the sampling time. For some cases, this distance is beyond the limits of the diagrams, and in such cases the area of most likely origin is not enclosed by an indicated upwind limit. In determining these areas, reported winds from stations 1, 3 and 8 were used primarily, with winds from stations 7 and 12 given secondary consideration.

Non-selective sample number 8 was collected on December 4, 1956 between 0930 and 0945 CDT. It was a large volume grab sample taken during break-up of a nocturnal inversion at a location near Rubbertown. It was not possible to determine the origin of the air parcel sampled because necessary types of meteorological data were not available. No figure is shown for this sample.


SECTOR OF MOST LIKELY ORIGIN OF AIR PARCEL.
LIMIT OF SECTOR OF POSSIBLE ORIGIN OF AIR PARCEL.
WEST END LOUISVILLE
RUBBERTOWN
N
1
2
3
4
5
6
7
8
9
10
11
12
LEGEND:
● POINT OF SAMPLE COLLECTION
○4 AEROMETRIC STATIONS

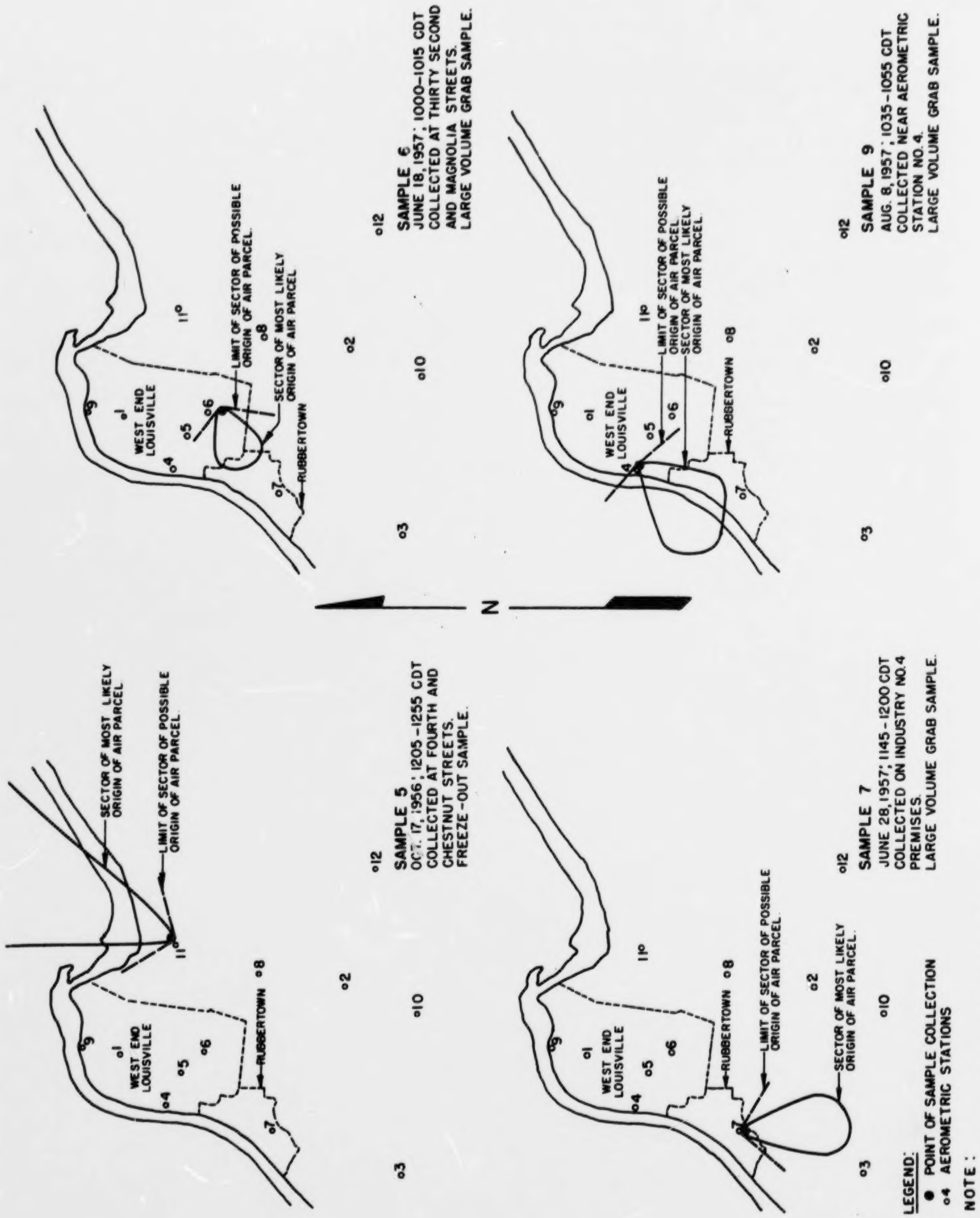
SAMPLE 1
OCT. 17, 1956; 1000-1050 CDT
COLLECTED AT FOURTH AND
CHESTNUT STREETS.

SAMPLE 2
OCT. 17, 1956; 0800-0850 CDT
COLLECTED AT FOURTH AND
CHESTNUT STREETS.

SAMPLE 3
OCT. 16, 1956; 1500-1600 CDT
COLLECTED AT FOURTH AND
CHESTNUT STREETS.

SAMPLE 4
OCT. 17, 1956; 1139-1222 CDT
COLLECTED ON LAKE DREAMLAND ROAD.

Figure 3-28. ORIGIN OF AIR PARCEL FOR NON-SELECTIVE SAMPLES (ALL WERE FREEZE-OUT SAMPLES)


SECTOR OF MOST LIKELY ORIGIN OF AIR PARCEL
LIMIT OF SECTOR OF POSSIBLE ORIGIN OF AIR PARCEL.
WEST END LOUISVILLE
RUBBERTOWN
1
2
3
4
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10
11
12
N
LEGEND:
● POINT OF SAMPLE COLLECTION
○4 AEROMETRIC STATIONS

SAMPLE 5
OCT. 17, 1956; 1205-1255 CDT
COLLECTED AT FOURTH AND
CHESTNUT STREETS.
FREEZE-OUT SAMPLE.

SAMPLE 6
JUNE 18, 1957; 1000-1015 CDT
COLLECTED AT THIRTY SECOND
AND MAGNOLIA STREETS.
LARGE VOLUME GRAB SAMPLE.

SAMPLE 7
JUNE 28, 1957; 1145-1200 CDT
COLLECTED ON INDUSTRY NO.4
PREMISES.
LARGE VOLUME GRAB SAMPLE.

SAMPLE 9
AUG. 8, 1957; 1035-1055 CDT
COLLECTED NEAR AEROMETRIC
STATION NO.4.
LARGE VOLUME GRAB SAMPLE.

NOTE:
METEOROLOGICAL DATA NOT AVAILABLE
FOR CORRELATION WITH SAMPLE NO. 8

Figure 3-29. ORIGIN OF AIR PARCEL FOR NON-SELECTIVE SAMPLES

Concentrations of pollutants peculiar to Rubbertown were greatest when samples were collected near and downwind from Rubbertown. Pollutants known (from source studies) to be emitted in major amounts were found also in ambient atmospheric samples collected by non-selective sampling. Some materials found on mass spectrometric analysis of non-selective samples were not accounted for in pollution source studies. Noteworthy concentrations of pollutants emitted from Rubbertown sources and found in these non-selective samples include the following: butadiene-1830 ppb; phenol-48 ppb; vinyl chloride-5850 ppb; acrylonitrile-336 ppb; chloroprene-218 ppb; toluene-270 ppb (Table 3-28).

Odor thresholds for only a few pollutants emitted in Rubbertown were available. Concentrations of several pollutants in the atmosphere were in excess of odor threshold values. Ratios of observed pollution levels to odor threshold concentrations ranged from one for phenol to 25 for gasoline (Table 3-29).

Summary of Findings from Measurements of Gaseous Pollutants

Aldehyde concentrations at stations C and D frequently exceed the eye irritation threshold of 250 ppb. Study of wind directions prevailing at times when aldehyde concentrations were high lead to the conclusion that power stations are probably the principal individual sources of this pollutant, although a burning dump and multiple sources, such as motor vehicles and fuel burning units (other than power stations), also are collectively responsible for high concentrations. Maximum concentrations of ozone reached 70 percent of the eye irritation threshold value and maximum allowable concentration for industrial workroom atmospheres. Maximum hydrogen chloride concentrations reached to nearly half of the maximum allowed for an industrial work-room.

Monthly mean values of daily maximum sulfur dioxide concentrations ranged from about 50 ppb in July to about 100 ppb in January. The taste threshold for sulfur dioxide (300 ppb) was exceeded on about half the days during the winter and about one-fifth of the days during the summer. The odor threshold (3000 ppb) was exceeded on one day during the winter and on one day during the summer. Sulfur dioxide values varied markedly with time of day, with highest concentrations occurring between 0600 and 1200 hours and lowest concentrations between 2400 and 0600 hours. The higher concentrations are due to high rates of fuel combustion and rapid mixing of stack discharges with air near the ground, including the well known "fumigation" pattern of dispersion which occurs as nocturnal inversions are being dissipated. Lower concentrations are due to low rates of fuel combustion and slow (if any) mixing of plumes from tall stacks with air near the ground.

Mass spectrometric analyses of non-selective gaseous pollution samples showed the presence of many gases in the atmosphere of downtown and West End Louisville and of Rubbertown which were known to be discharged from Rubbertown industries and other sources and also some additional pollutants. Concentrations of a number of gaseous pollutants were far in excess of odor threshold values.

AIR QUALITY IN RELATION TO METEOROLOGICAL VARIABLES

The aerometric portion of the Louisville study sought to determine patterns of occurrence of pollutants, both geographically and on a time scale, and to relate these findings to the sources of pollutants.

Consideration of air pollutant concentrations as a function of wind direction provided useful information on the contribution of given sources to points of reception. The emission and dispersion of pollutants act together in determining concentrations, and for a given receptor (sampling) location, wind direction takes into account both these factors, so that the effect of sources as a function of direction is provided by relationships of pollutant concentrations with wind direction alone.

Relationships between air quality and meteorological variables other than wind direction presented here represent, for the most part, limited analyses of selected data made for the purpose of [illegible] meteorological [illegible] be related [illegible] data [illegible] that exist.

Wind Direction

To show relative effective source strengths as a function of direction from a given sampling location, comparisons of the frequencies with which winds from a given direction were observed during periods of high and low pollution concentrations were made. "High" and "low" concentrations may be defined as being above or below certain limits such that the limits are exceeded by only a chosen fraction of the measured values. Periods were selected on the basis of suspended particulate concentrations measured by use of high volume samplers. For each sampling station, each eight-hour sampling period was classified according to whether the concentration was high, low, or moderate. Frequencies of concurrent wind directions at one or more wind measuring stations for each classification were then obtained. The percentage ratio (r) for a selected category (high or low) for each direction was obtained from the following expression:

$$r = 100 \quad \frac{n_s \ N_t}{n_t \ N_s}$$

where n_s is the frequency of winds from the given direction during the periods classified within the selected category,

n_t is the frequency of winds from the given direction during the entire interval of record considered,

N_t is the frequency of observations during the periods classified as within the selected category, and

N_s is the total number of observations during the interval of record considered.

Thus, if the occurrence of winds from a given direction were unrelated to measured suspended particulate concentrations, the computed ratio or index would be 100 percent; if no winds from the given direction occurred during the selected periods, the ratio would be zero percent; and if all the winds from the given direction occurred during the selected periods, the ratio would be at its maximum value, or 100 N_t/N_s.

Sampling periods were selected by three similar methods. In the first, periods of the eight highest and eight lowest total suspended particulate concentrations were selected separately for each of the three daily sampling periods and for each of the three months considered; in the second method, data for each daily sampling period for the three months were grouped, and the periods of 24 highest and 24 lowest concentration values were selected separately for each period. In both of these methods 72 periods of high and 72 periods of low concentration were selected from a total of approximately 270 sampling periods, so that the selected periods represent approximately the upper and lower quartiles of the distribution of air quality values. These methods yielded results so nearly identical that no further distinction will be made between them. The third method will be described later.

The observed frequencies were then adjusted for missing wind direction observations. The bulk of the observations recorded as missing from stations 1, 3, and 8 were not actually missing, but, due to the equipment used, were indeterminate in a sector centered on east (See Figure 2-1 for location of stations). For each of these stations, a count was made of the number of hours of wind direction recorded missing, separating such hours into categories of indeterminate and actually missing (due to such causes as equipment failure, maintenance shutdown, etc.). The number of indeterminate direction observations was added to the observed direction frequencies between northeast and southeast in such a way that the percentages of assumed indeterminate observations were in a ratio of 1:4:6:4:1 for the directions northeast, east-northeast, east, east-southeast, and southeast respectively. Minor departures from precise ratios were necessary to yield a sum of assumed indeterminate observations equal to the known total. The frequencies for all classes of concentrations (upper, lower, and total) were adjusted in this manner. Finally, for each wind measuring station, observations actually missing were distributed among the directions according to the adjusted frequencies obtained above, so that the adjusted total number of observations used to derive each figure was the total number of hours in the interval of record considered times the numbers of wind stations considered. There were a few periods of missing particulate concentration values; the effect of the above procedure was to assume that such periods would have been periods of moderate concentration.

The third method for selecting sampling

periods was as follows. For each of the three daily air sampling periods (2400-0800; 0800-1600; 1600-2400), the appropriate punch card deck containing both wind and air sampling data was divided into three categories, representing the lower and upper quartiles, and the central quartiles of total particulate concentration. The quartile divisions were not exact; all cards containing the same concentration value were included in the extreme quartiles if one or more cards with that value fell in those quartiles, e.g. for station 3, summer, there were 928 hours of low, 944 hours of high, and 1792 hours of moderate concentrations. The cards for all three air sampling periods for a given category of particulate concentration were counted together to obtain wind direction frequencies for that concentration category. Wind direction ratios were then computed from these frequencies with no adjustments for missing data. This procedure in effect assumes that there is no air quality-directional bias in the recorded missing wind directions, whereas, actually there is a tendency for easterly winds to be more associated with periods of higher concentration. Since periods of missing air quality data are excluded from consideration, there is no bias introduced from that source.

High and low wind direction ratios are not by definition related, although generally a direction showing a large ratio for high sampling will show a small ratio for low periods, and vice versa. A direction with a small ratio for both high and low categories indicated that the concentrations observed with winds from that direction were more clustered about the median values, and may be indicative of either a moderate effective source in that direction, or a transitional influence, where winds from that direction occurred during periods when winds from adjacent stronger and weaker effective sources also occurred. Real differences between adjacent directions would tend to be somewhat obscured by the variations in wind direction that may occur during an eight-hour interval.

As is true for all relationships between a single meteorological element and air quality prameters, the indications given are a mixture of the net influence of the particular meteorological element considered and the additional influence of all other meteorological parameters, which may vary more or less systematically with the element under consideration. The indications of relative effective source strength given by the wind direction ratios are valid, however, except for those cases with only a few observations, namely easterly or southeasterly winds at all surface wind stations except station 12, and possibly 8.

From Figures 3-30 to 3-32, it can be seen that there is a general tendency for easterly winds to be associated with higher total particulate concentrations, and westerly or northwesterly winds with low concentrations, a reflection of the tendency for east winds to occur during or following the passage of cells or ridges of high pressure, with generally light winds and a subsiding stable air mass, and west or northwest winds to occur as fresh

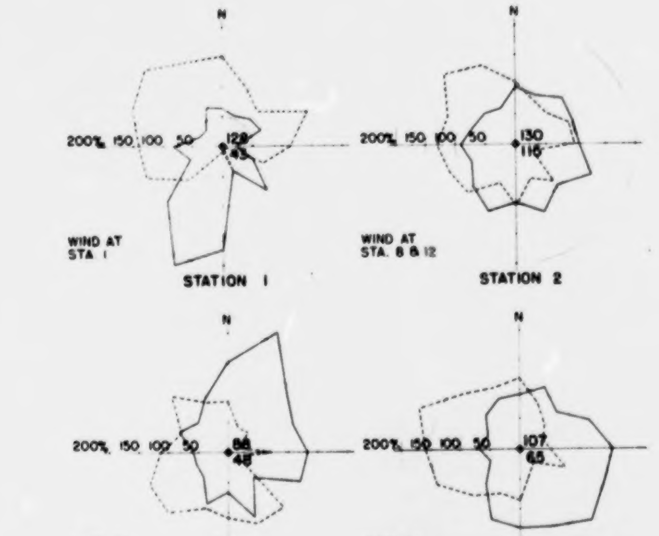

Figure 3-30. WIND DIRECTION RATIOS DURING PERIODS OF HIGH AND LOW TOTAL SUSPENDED PARTICULATE POLLUTION JULY - SEPTEMBER, 1956

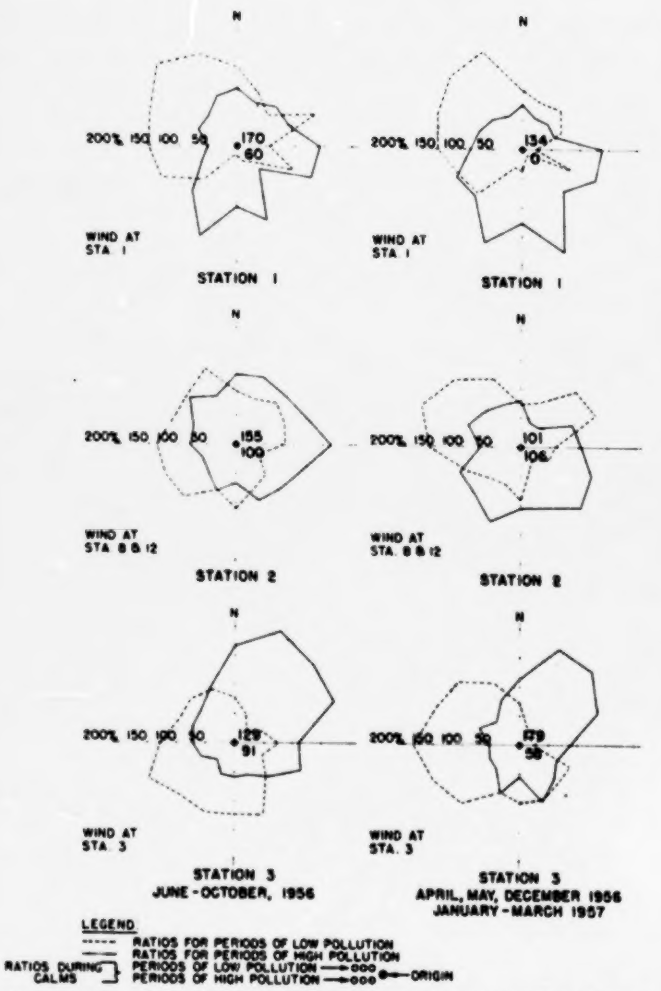

Figure 3-31. WIND DIRECTION RATIOS DURING PERIODS OF HIGH AND LOW TOTAL SUSPENDED PARTICULATE POLLUTION FOR STATIONS 1, 2 AND 3 FOR TWO TIME PERIODS

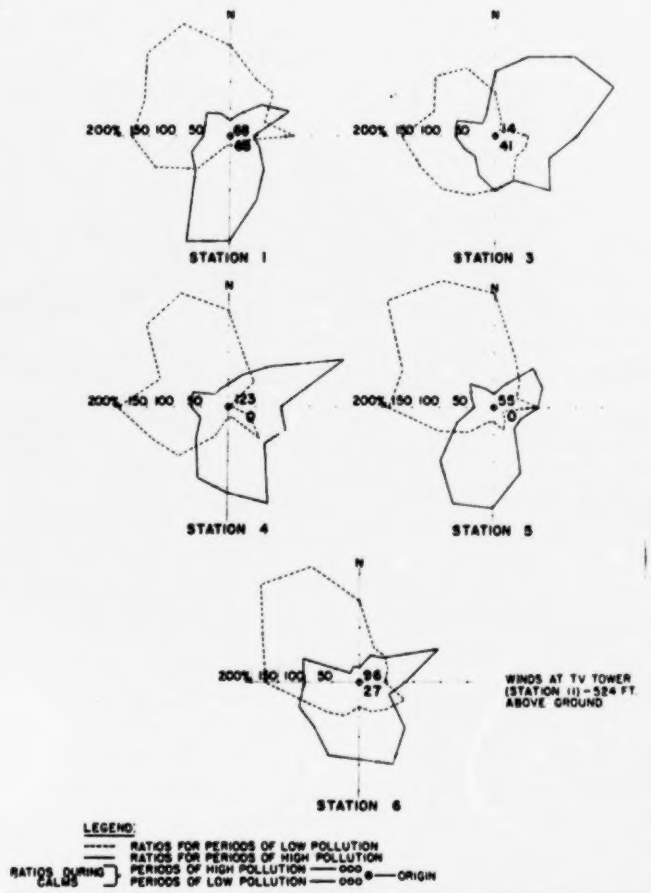

Figure 3-32. WIND DIRECTION RATIOS DURING PERIODS OF HIGH AND LOW TOTAL SUSPENDED PARTICULATE POLLUTION JULY - SEPTEMBER, 1956

outbreaks of cool unstable air move across the area. The influence of presumed sources of particulate matter are superimposed on and distort this general pattern. Except for station 2, the direction representing flow from Rubbertown are observed much more frequently with high concentrations than with low (Figures 3-30 to 3-32). At station 1 during intervals of prevailing south or south-southwest winds, the occurrences of higher concentrations with flow from Rubbertown so predominated as to give little or no real indication of any other sources. This predominance of Rubbertown is reduced somewhat by considering other intervals of record.

At station 3 there are weak suggestions of two other sources. The ratio for low cases decreases, and for high cases increases slightly for the directions south or south-southwest, and more noticeably for the direction west-northwest. The former is a possible effect produced by a cement plant located at Kosmosdale, while the latter is most likely an effect of Rubbertown industry number 7.

At station 4, the distinction between flow from urban and non-urban areas was most marked; at station 5, the influence of Rubbertown sources was more predominant; while at station 6 effective sources covering most of the southern semicircle from that station were apparently of influence, at least during the three-month interval of record considered. Generally, the ratios for winds at the TV tower (station 11) showed a clearer distinction between flow from Rubbertown and flow from adjacent directions than did the ratios computed from surface wind measurements, indicating that the high-level winds provided a better representation of transport from the elevated sources of particulate matter in Rubbertown to the sampling sites than did the surface winds (Figure 3-32 compared to 3-30 and 3-31). For these sources, a resultant wind based on proper weighting of both surface and upper level wind measurements would provide the clearest directional distinction.

Station 2 showed no particularly pronounced directional influence, the only consistent effect being that southeasterly winds showed a large ratio for high cases, and a small ratio for low cases. Considering the location of this site with respect to the urban areas, it might be expected that winds from a southwesterly direction should be predominantly associated with low concentrations. The absence of this association is probably due to the rather frequent occurrence of dust raised from the ground surface by the wind, with this effect being particularly noticeable in the spring months of 1956, after a new highway near the station had been completed, but not sodded along the embankments. At this station, some of the highest and lowest total particulate concentrations were observed under nearly identical conditions of strong and gusty southwest winds. The indications of an influence by Rubbertown pollution sources are very weak at this station, with only a slight increase in the ratio for higher concentrations, and a slight decrease in the ratio for lower concentrations for west-northwest or northwest winds. These changes are so slight as to be well within the limits of uncertainty of the data.

Wind direction ratios were computed for selections based on organic particulate concentrations for one location (Figure 3-33). The major influence is apparently the relationship between the gross weather pattern and wind direction, such that periods of higher concentration of organic particulates tend to occur with winds centered on southeast, and periods of lower concentration are more associated with west or northwest winds. Although winds from Rubbertown directions more frequently occurred during periods of higher concentration, Rubbertown does not appear to be the major source of organic particulate matter. It appears that pollution sources throughout the community act as an area source, with the effect of the area source modified by the gross weather correlation noted previously.

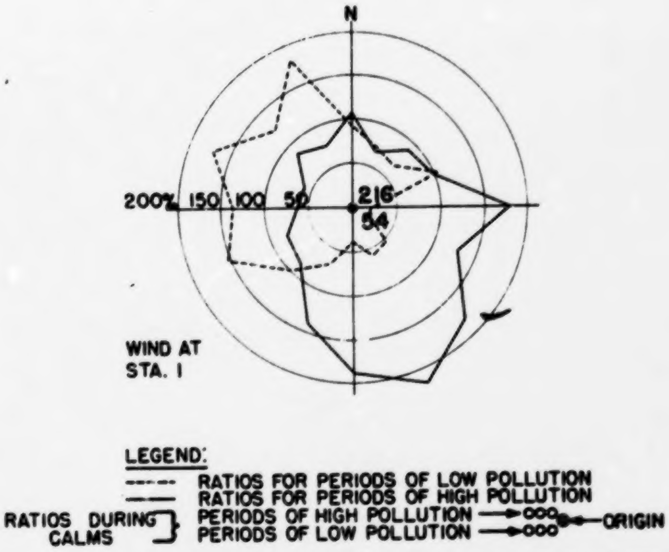

Figure 3-33. WIND DIRECTION RATIOS DURING PERIODS OF HIGH AND LOW CONCENTRATIONS OF ORGANIC MATTER IN SUSPENDED PARTICULATE POLLUTION; STATION 1 FEBRUARY - APRIL 1956

Wind Speed

The total influence of wind speed on air quality determinations is quite complex. Relationships developed depend on season and time of day and on the measure of air quality considered, which in turn is a reflection of the nature and distribution of the sources of the pollutant being measured. As a result, for a given sampling location the relationship between concentration and wind speed may vary with wind direction.

The most extensive comparisons made between wind speed and air quality measurements involve concentrations of total suspended particulate material as determined by use of high volume samplers. Primary attention was given to samplers located in the West End (stations 1, 4, 5, and 6 - see Figure 2-1 for locations), although the other two locations (stations 2 and 3) were considered also. For the bulk of the data, no direct sustained relationship between wind speed and total particulate concentration was found. One example of the lack of direct relationship is shown in Figure 3-34 in which all three sampling periods and all wind directions are considered together. When the different periods of the day were considered separately, or when wind direction was restricted to represent flow

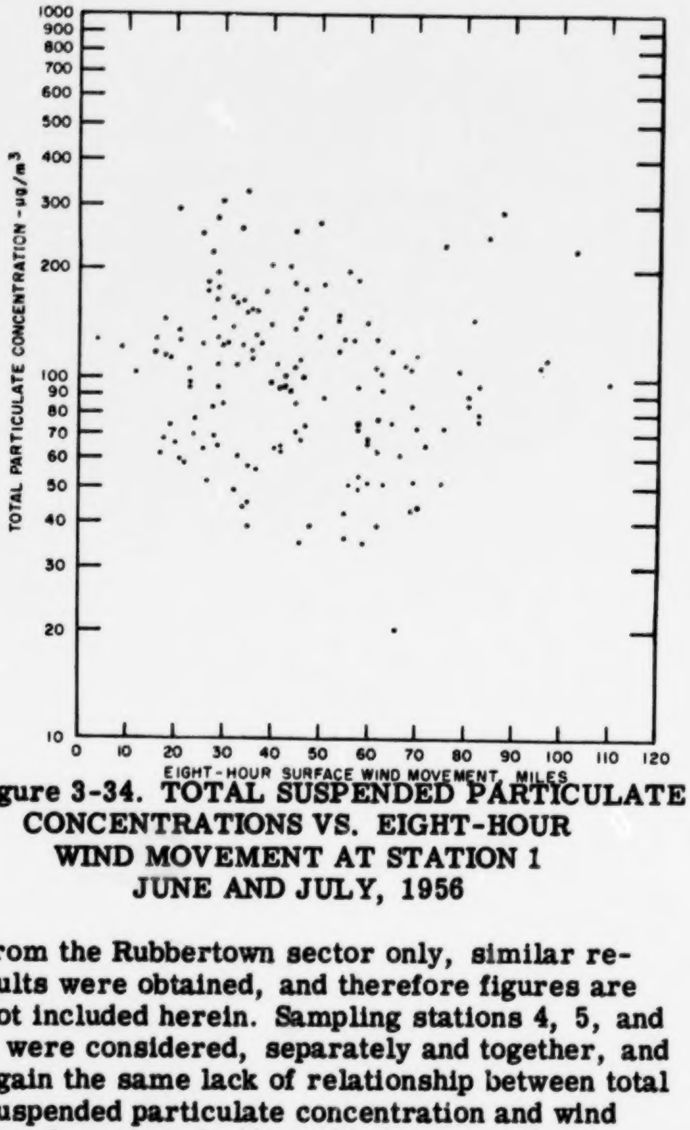

Figure 3-34. TOTAL SUSPENDED PARTICULATE CONCENTRATIONS VS. EIGHT-HOUR WIND MOVEMENT AT STATION 1 JUNE AND JULY, 1956

from the Rubbertown sector only, similar results were obtained, and therefore figures are not included herein. Sampling stations 4, 5, and 6 were considered, separately and together, and again the same lack of relationship between total suspended particulate concentration and wind speed was noted. About the same result was found for other seasons of the year. It must be concluded that there is no consistent relationship between wind speed and concentrations of total suspended particulate at the West End sites. This is not to say that wind speed is not a factor influencing concentrations of total particulate, but rather it appears that wind speed has several influences, the sum of which yields no consistent relationship. It may be noted in Figure 3-34 that the higher concentrations (over 200 µg/m³) occurred with wind speed groupings of 2-6 mph and 10-12 mph, representing two different weather types. The low wind speed grouping was a nighttime phenomenon, representing generally stable conditions. The four high wind speed cases were daytime occurrences, although in other months, particularly in winter or spring when stronger winds at night were more frequent, the high wind-high concentration occurrences were not limited to daytime periods.

At stations 2 and 3 a small wind speed influence on concentrations of total particulate was shown to exist with lower concentrations tending to be more associated with higher wind speed occurrences. The association is weak, however, and in fact the highest concentrations measured during the study at station 2 occurred during the daytime with strong winds, and probably represented wind-blown dust from the new highway near the sampling site.

Wind speed ratios analagous to the wind direction ratios shown in the previous section were devised for two seasonal groupings at three sampling stations (Table 3-30). At station 1, both the lower and higher wind speed occurrences tended to be more associated with higher concentrations of total particulate, rather than lower concentrations, with this tendency somewhat more pronounced during the summer. At station 2 and 3, the general tendency for association of higher wind speeds with lower concentrations is more evident, more so during the winter. The slight seasonal difference suggests that, if the ground surface is dry, higher winds may pick up particles from the ground, thus leading to higher measured concentrations. At stations 1 and 3, the lack of association of decreased concentrations with increased winds was more evident with winds from the direction of Rubbertown to these stations, whereas at station 2 the decrease of concentrations with increasing winds predominated with flow from the direction of Rubbertown. Taking into consideration the frequencies and especially the persistence of flow from Rubbertown towards each of the three sampling stations, the effects of wind speed with flow from the Rubbertown area to each of these stations is consistent with the interpretation that particles emitted from the Rubbertown area fall to the ground, and may be picked up again by stronger winds and collected by the samplers.

Concentrations of organic material show a

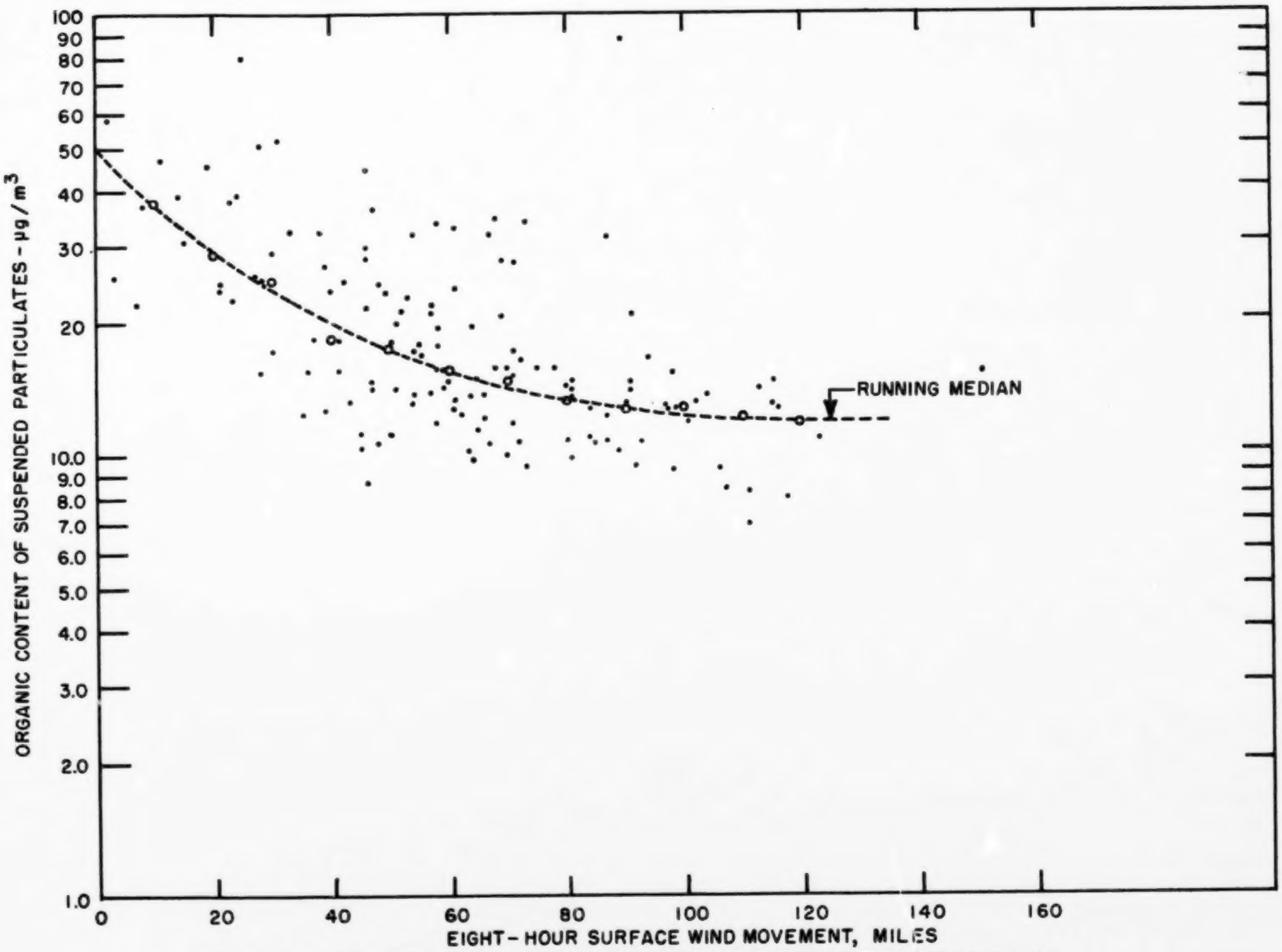

Figure 3-35. ORGANIC CONTENT OF SUSPENDED PARTICULATE MATTER VS. EIGHT-HOUR WIND MOVEMENT AT STATION 1 FEB. AND MAR., 1956

definite wind speed influence (Figure 3-35 and 3-36), with high concentrations generally associated with light winds, and low concentrations with strong winds. The association between organic concentrations and wind speed was better defined during the winter months than during the summer. A more pronounced association has also been noted for nighttime periods than for daytime periods; the relationship between wind speed and organic concentrations during daytime periods is not particularly different from the lack of relationship shown (Figure 3-34) between total particulate concentrations and wind speed, whereas, in general, the relationship for nighttime periods tends to be more similar to that shown by Figure 3-35. The associations of organic concentrations with wind speed noted are generally valid for all sampling stations, with the possible exception of station 3; at this site, there seemed to be some transient influence such that, on some occasions, higher winds speeds were associated with comparatively high organic concentrations.

More limited analyses have indicated that the optical density measurements made with the AISI strip filter paper sampler show a relationship to wind speed very similar to the relationships between organic concentrations and wind speed. An example is shown later as part of a more general analysis of these air quality data.

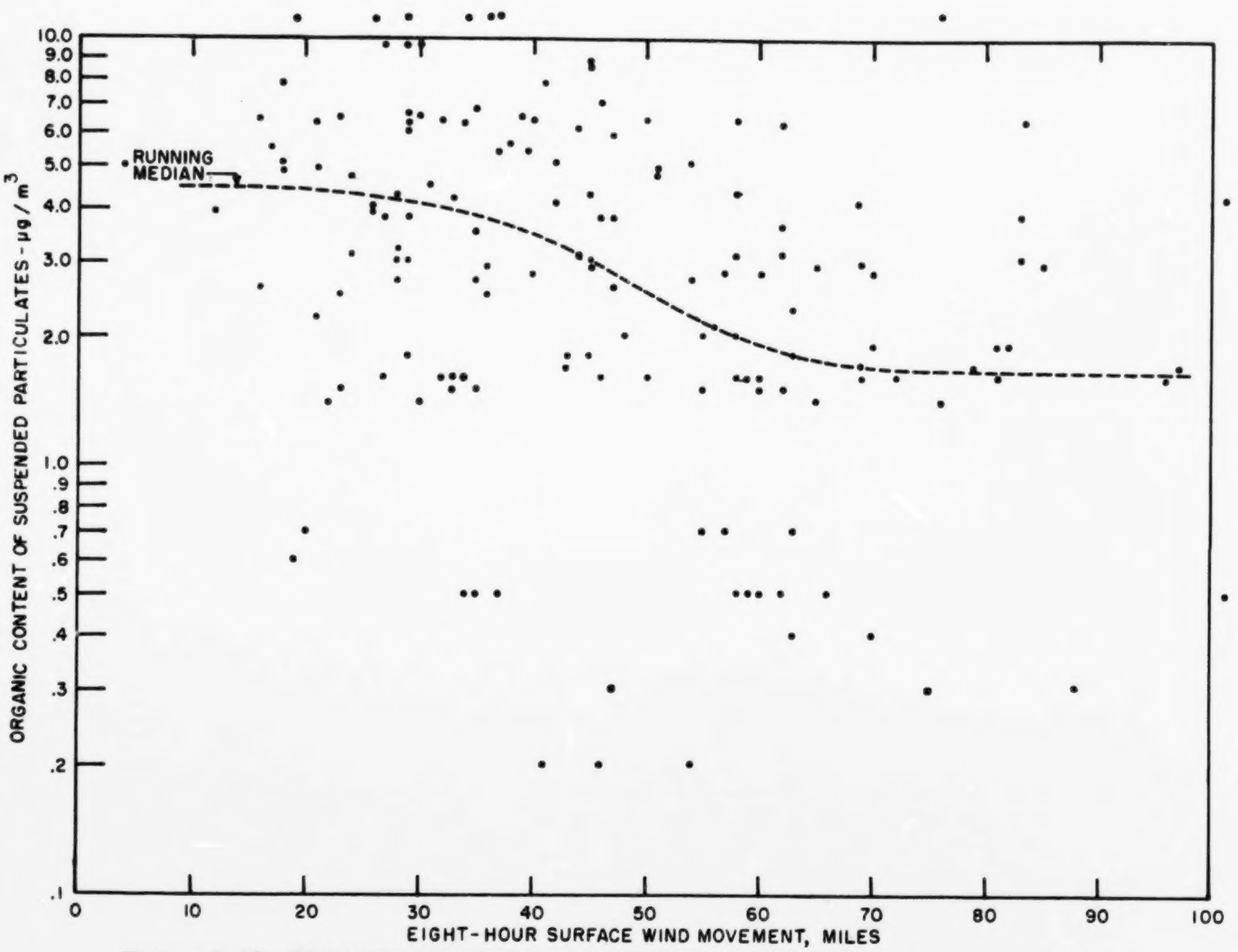

Figure 3-36. ORGANIC CONTENT OF SUSPENDED PARTICULATE MATTER VS. EIGHT-HOUR WIND MOVEMENT AT STATION 1 JUNE AND JULY, 1956

Temperature

Because of the increased heating requirements in colder weather, temperature of the air should be related to concentrations of certain substances, emitted to the atmosphere from space heating units. A number of air quality variables: total suspended particulate; organic particulate; sulfur dioxide; and optical density, have been compared, for small intervals of record, with hourly temperatures, daily mean, and weighted lagged daily mean temperatures. Any direct simple relationships that may exist between these parameters are apparently so slight as to be obscured by other influences. However, when average values over a sufficiently long time period are considered, parallel trends between mean temperature, expressed as normalized monthly degree day totals, and several air quality variables are evident (Figure 3-37). Mean organic concentrations and mean optical density values show a five-fold change from summer minimum to winter maximums; sulfur dioxide a variation slightly more than double, and total particulate concentrations almost no variation. Heating requirements therefore appear to have a definite effect on organic particulate concentrations and optical density values, a lesser effect on sulfur dioxide concentrations, and essentially no effect on total particulate concentrations.

The period of averaging required to bring out this relationship was investigated by comparing 1-, 5-, 10-, and 20-day mean organic concentrations measured at sampling stations

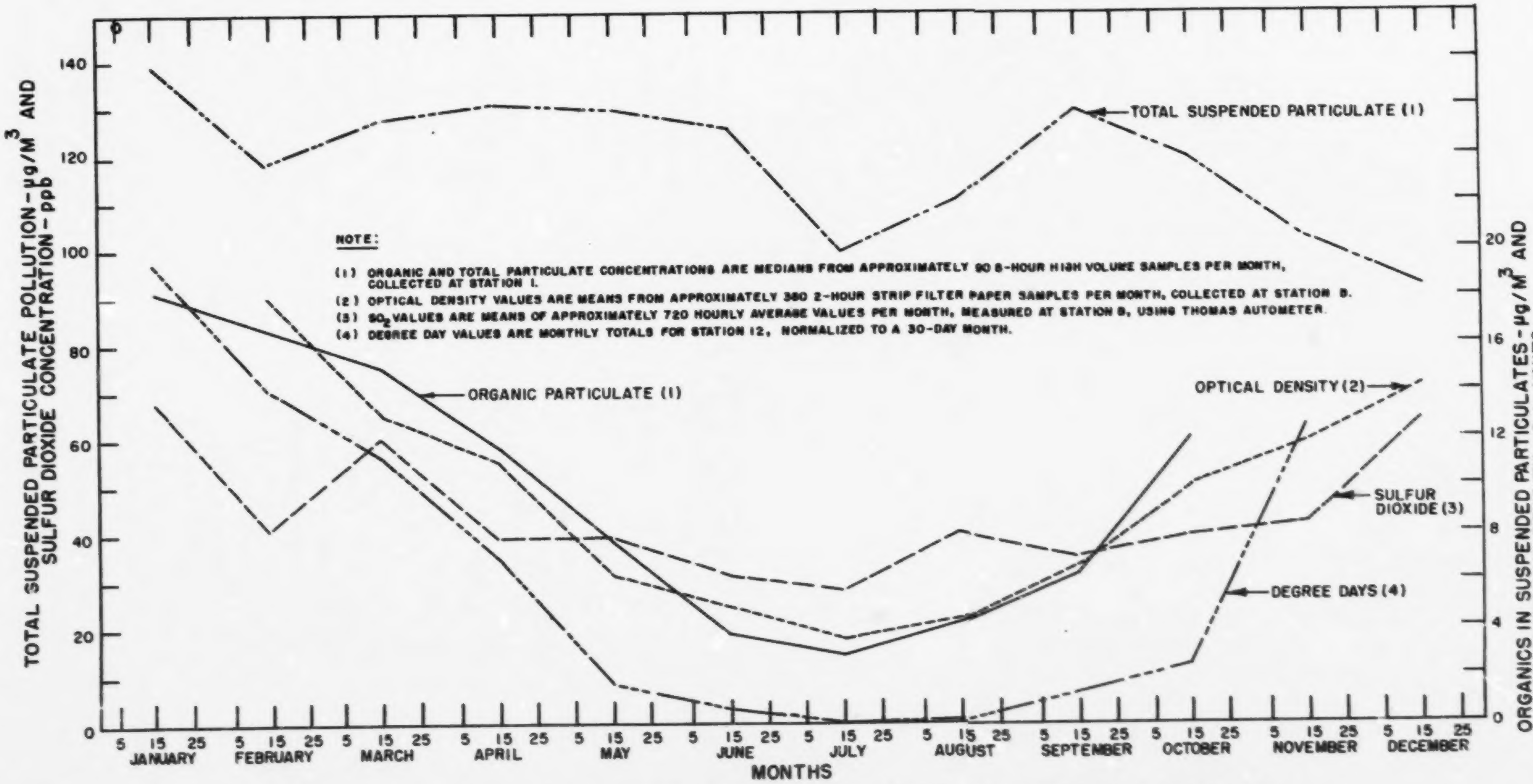

Figure 3-37. MONTHLY DEGREE DAYS VS. AIR QUALITY MEASUREMENTS; 1956

1 and 2, with mean temperatures at station 12 for the interval of record beginning with the start of sampling operation at each station and extending through June 1956. The only evident relationship for averaging times of up to ten days was that high mean concentrations did not occur with high mean temperatures, reflecting the divergent seasonal trends of temperatures and organic concentrations. Averaging times of 20 days, however, showed essentially an inverse linear relationship for mean temperatures below 65-70 degrees F. It is very probable that optical density data would show the same relationships as a function of averaging time.

The parallel trends shown between degrees days and mean concentrations is most likely a response to the annual cycle of temperature, and thus is a causually explainable relationship. However, the major component of the relationship appears to be indirect, and is a reflection of the annual cycle of activities in response to the normal annual temperature cycle. Short period deviations of temperature have only a minor detected influence.

Attempts were made to select days during different months in which the same meteorological pattern, including the same temperatures, existed; comparison of organic concentrations and optical density measurements between such days (as nearly as could be obtained) supported the general relationships noted. Differences in concentrations between similar days with different temperatures, occurring within periods up to a few weeks apart, were essentially random. There was some indication of the temperature influence when the sequences of temperatures and concentrations were considered. During April and May, each successive warm spell (with daytime temperatures above 80 degrees F) seemed to be followed by a decrease of concentrations, such that concentrations during successive periods of intervening cooler weather showed a sustained decrease. A comparable trend under opposite weather cycles has been noted for soiling index measurements made in Cincinnati during the autumn--that is, a sustained rise in the measured values seems to follow each successively cooler period of weather in September and October.

Precipitation

Air quality should be influenced by the occurrence of precipitation for two reasons. The direct influence of precipitation is to wash the air, scavenging material from the air by direct collision with, or entrainment of particles in the air, and acting as a surface on which gaseous matter may collect. The amount of material removed from the air should therefore be dependent on the time interval through which precipitation is effective, on the physical characteristics of the material being removed, and the characteristics of the precipitation, such as the size, number, and rate of fall of precipitation elements (rain drops etc.). The occurrence of precipitation has an additional indirect effect on air quality in that atmospheric processes taking place during periods of precipitation, differ from those during periods of non occurrence of precipitation, so that it is not possible to determine the amount of washout by comparing periods of precipitation with "similar" periods of no precipitation.

A comparison of air quality before and after periods of precipitation does not provide an indication of the direct influence of precipitation, for somewhat different reasons. Precipitation most frequently occurs near moving boundary zones between different air masses, with the result that a different air mass is generally present after precipitation ends than was present when the precipitation began. A comparison of this type would tend to show differences in air quality as a function of different air masses, rather than the direct effect of precipitation. The more infrequent occurrence of precipitation with no change of air mass would be associated with local showers, in which event the air present following the showers would quite likely not have been within the shower area prior to its arrival at a sampling point, since the area covered by a given shower cell is comparatively small. In any event, changes of concentration due to changes in the rate of dilution of locally emitted pollutants are likely to be as great or greater than the concentration within the general air mass (the exotic pollution) that might be washed out by precipitation, so that the indirect effects of the occurrence of precipitation would tend to obscure the direct effect.

The total effect of precipitation was examined for the air quality variable which would be expected to show the maximum direct effect, namely, concentrations of total suspended particulate matter. To remove a possible bias due to a parallel trend between occurrences of precipitation and concentrations, on either a diurnal or month-to-month basis, concentrations were converted to a relative percentage concentrations by dividing the measured concentrations by the median concentrations for the given station, month, and period of the day, and multiplying this ratio by 100. For each air sampling-rain gage station the three daily sampling periods were examined separately. As different results were not obtained for different times of day, the results were grouped into the two seasonal classes of summer and winter. Since nearly all the plotted data gave no indication of influence of precipitation on particulate concentrations, the data are not presented here.

Only at station 1 during the winter months (Figure 3-38) did the duration, although not the amount of precipitation, show any suggestion of an influence on relative concentrations, with a tendency for lower concentrations to occur during periods of greater duration of precipitation. Relative concentrations during periods of no precipitation would be approximately normally distributed about the 100 percent line on the figure.

Regressions and Correlations of Optical Density with Meteorological Parameters

A small sample of the data collected during the course of the study was analyzed to show the relationships of optical density (soiling index) measurements to meteorological parameters using graphical multiple curvilinear regressions and correlation indices.[36]

The relatively short (2 hour) sampling period assisted in maintaining uniformity of the values of the meteorological parameters within the sampling period. Data representing the early morning period of the day (0000 - 0500 CST) would minimize the effect of the diurnal trends of optical density measurements and meteorological parameters. In this analysis, soiling measurements for station B for the period 0000 to 0200 CST during February, March, and April 1956 were used.

The meteorological parameters used in this analysis were wind speed, wind direction, temperature, and a stability index. The wind speeds, wind directions, and temperatures used were means of the two hourly average values for the sampling period. The stability index is the difference between the mean of the daytime maximum temperatures before and after the sampling period, and the mean temperature during the sampling period, plus the change in maximum temperatures:

$$S.I. = 1/2\,(T_{x_1} \div T_{x_2}) - T_n \div (T_{x_2} - T_{x_1})$$

where S.I. is the stability index, T_{x_1} is the maximum temperature on the previous day, T_{x_2} is the maximum temperature on the day of the sample, and T_n is the mean temperature during the sampling period. Low values indicate instability and high values, stability. The meteorological measurements were made at station 1.

The optical density data were divided into two groups, one group to be used to estimate graphically the regression curves and the other to check the representativeness of the graphical estimates for independent data from the same population. The data were divided by first ranking the optical density measurements and then by placing the odd-numbered rank values into the first group and the even-numbered values into the second group. The optical density data with missing meteorological data for the same time period were eliminated. Forty-two cases were used to derive the relationships and thirty-four cases were used for checking purposes.

The regressions and intercorrelations (Table 3-31) among the meteorological parameters, and the regression (Figure 3-39 to 3-42) and correlation (Table 3-32) of optical density on each meteorological parameters were computed. A graphical curve-fitting method was used to estimate the regression curves. For each pair of parameters, except those which contain wind directions, the regression curves were first approximated by plotting a scatter diagram and graphically calculating and plotting moving median values of one parameter for an interval of the other parameter. Then a smooth curve of best fit was drawn to these moving medians (Figure 3-39, 40, 42). The regression values on wind direction are weighted moving average values (Figure 3-41), computed from the individual values for the wind direction under consideration, and the values for one compass point on either side of the direction under consideration. These averages are twice the sum of the values for the direction under consideration plus the sum of the values for the adjacent directions, divided by the sum of twice the number of observations for the direction under consideration and the number of observations for the adjacent directions. The correlations and

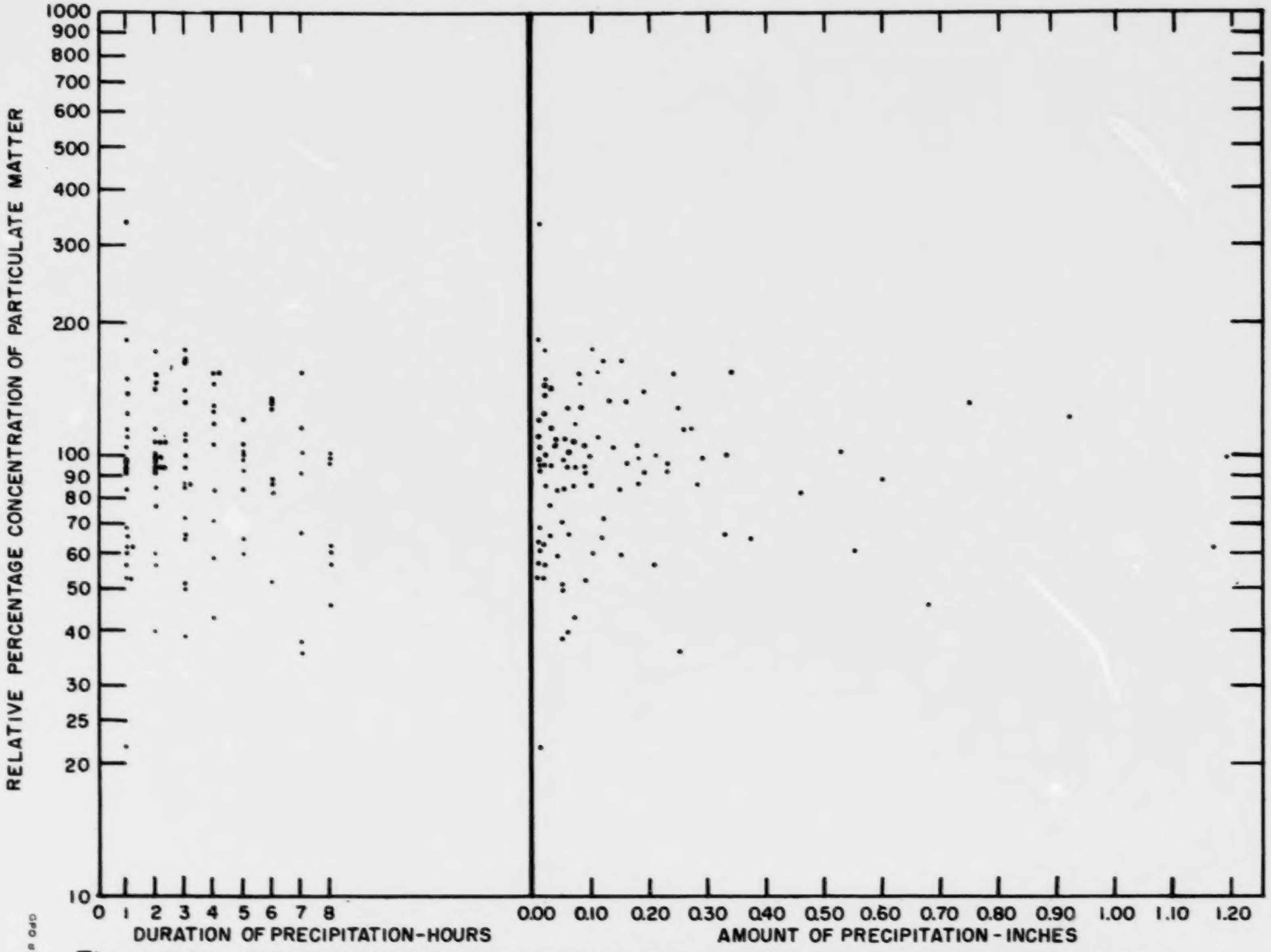

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Figure 3-38. RELATIVE CONCENTRATION OF TOTAL SUSPENDED PARTICULATE MATTER VS. DURATION AND AMOUNT OF PRECIPITATION DURING SAMPLING PERIODS; STATION 1 DECEMBER 1956 - APRIL 1957 (SAMPLING PERIODS 1, 2, AND 3)

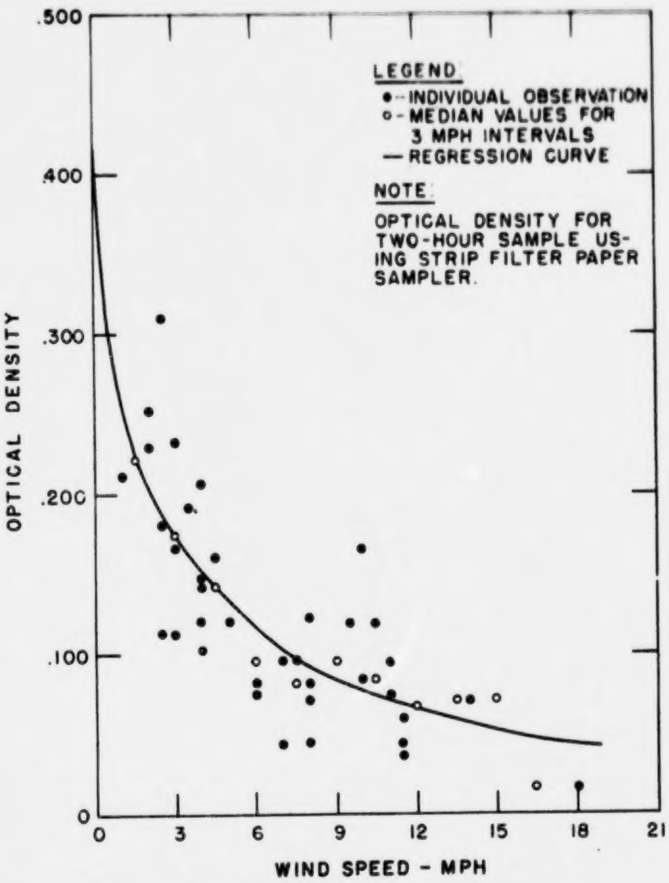

Figure 3-39. OPTICAL DENSITY VS. WIND SPEED

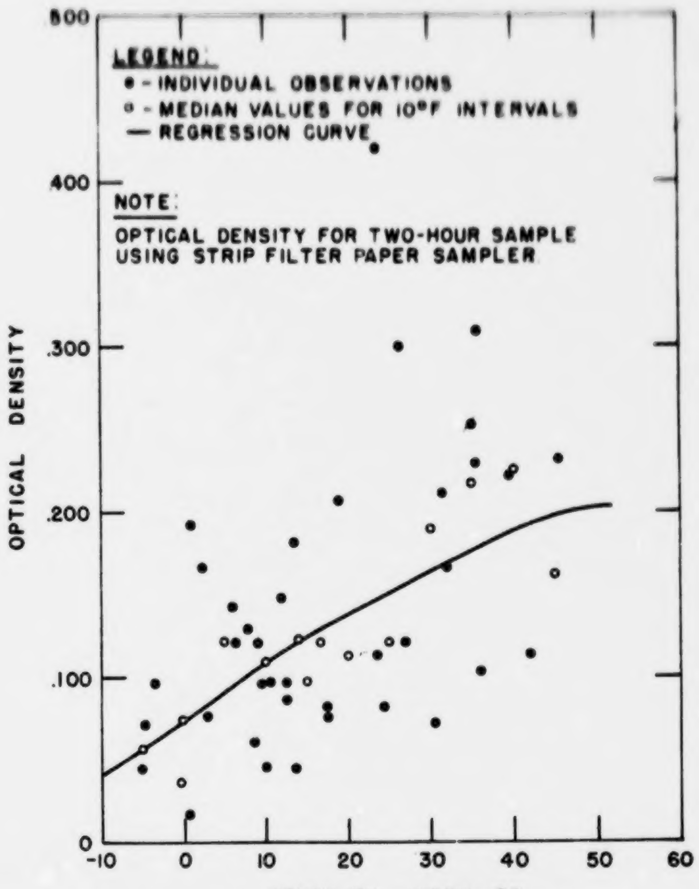

Figure 3-40. OPTICAL DENSITY VS. STABILITY INDEX

percents of variance explained were then computed to show the total relationships of each variable to every other variable used in the study.

Two graphical multiple curvilinear regression techniques were used to show the net effect of each meteorological parameter and the total effect of all of the meteorological parameters on optical density. Both techniques considered optical density as the dependent variable and the meteorological parameters as independent variables. In each of the techniques, a regression curve was drawn for the dependent variable on the first independent variable. The relative residuals (the ratio of the observed value minus the regression value to the regression value), were then computed and plotted against the next independent variable. A regression curve of the relative residuals from the first regression curve versus the second independent variable was drawn. This procedure was continued until the net effect of each independent variable was eliminated. The same procedures for drawing of regression curves, previously described, were used in both techniques. Cumulative correlation indices and cumulative percents of variance explained were computed after the elimination of the effect of each independent variable so that computation could be made of the net percent of variance explained by each independent variable after elimination of the effect of the preceding independent variables. The net variance explained by each independent variable after elimination of the effect of the preceding variables was then computed by subtracting the variance explained by the previous variables from the variance explained, including the variable in question. Also, standard errors of estimate (S_y) were computed for each correlation index.

The first technique presents two orders of variable elimination, one of which was selected because of its relationship to the statistical method and the other because of its relationship to air quality. Only first approximation regression curves were drawn so that the order of variable elimination would be significant.

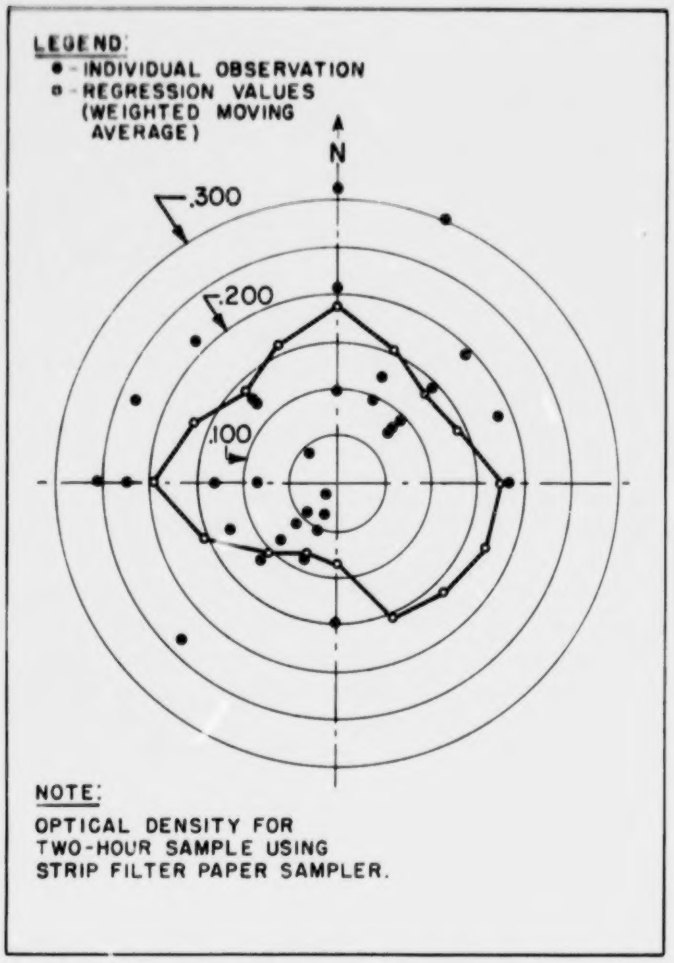

Figure 3-41. OPTICAL DENSITY VS. WIND DIRECTION

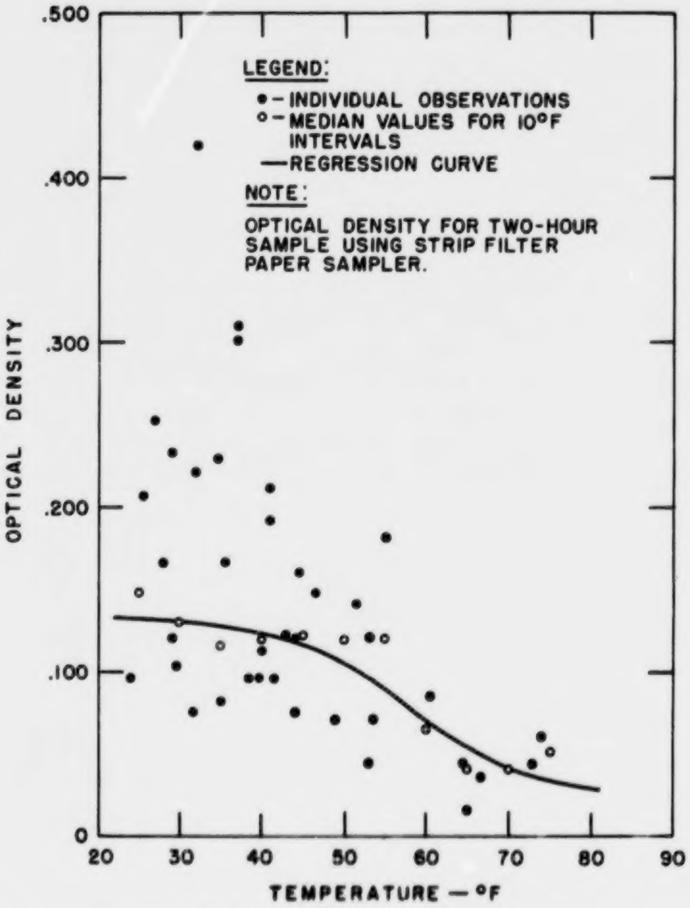

Figure 3-42. OPTICAL DENSITY VS. TEMPERATURE

The first order eliminates the effect of each independent variable according to its total influence on optical density, as determined by the correlation indices in Table 3-32. The order was wind speed, stability index, wind direction, and temperature (Table 3-33).

The second order eliminates the effect of each independent variable according to its assumed general relationship to air quality. The meteorological variables related to effective air pollution source strength are temperature and wind direction, and the variables affecting the dispersion of pollutants are wind speed and stability. Because the dispersion variables were eliminated first in the previous order of elimination, the source variables were eliminated first in this order. Therefore, the order was temperature, wind direction, wind speed, and stability index (Table 3-33).

The second technique used the multiple graphical curvilinear regression method, after Ezekiel.[37] This method involves a series of successive approximations which adjust the first approximation regression curves until no further adjustment can be made graphically. The method produces a net regression curve for each independent variable from which the effects of all of the other independent variables have been eliminated. Each curve is independent of order of elimination. Therefore, this method will show the net variances of optical density explained by each meteorological variable which are independent of order (Table 3-33).

Checks to determine the representativeness of the regression curves for a set of independent data were made by computing the standard errors of estimate (S_y') after the elimination of each independent variable (Table 3-34) and the total correlation indices for each technique (Table 3-35) of the second group of data on the sets of regression curves obtained in the two multiple regression techniques.

Wind speed explains considerably more of the variance of optical density, in its total effect, than any of the other meteorological parameters, and it explains approximately half of the variance of optical density in its net effect after elimination of the effect of the other meteorological parameters. All of the regression curves relating wind speed to optical density have the same characteristics. Since a check of these regression curves with independent data shows that standard errors of estimate decrease when progressing from the preceding step to the step which relates wind speed to optical density (Table 3-34), the form of relationship shown by the curves is valid.

Stability index ranks second in total influence on optical density. However, with the removal of wind speed effect, the amount of variance eliminated by stability is reduced considerably. Unlike the wind speed relationships, the characteristics of the stability index regression curves are not similar in all of the methods of analysis. According to the check of these regression curves with the independent data, they are not representative because the standard errors of estimate do not decrease, when progressing from the preceding step to the step which relates stability index to optical density.

Wind direction ranks third in both total and net effect on optical density. After elimination of the effect of the other meteorological parameters, the variance explained by it is reduced. The regression curves relating wind direction to optical density are fairly consistent but, according to the check with independent data, the regression curves are not representative for the same reason that was described in the previous paragraph on the stability index parameter.

Finally, temperature ranks last in total effect on optical density with considerably less net influence. However, all of the regression curves relating temperature to optical density have the same characteristics and these curves are representative when checked with the independent data.

The total correlation index obtained is highest with the successive approximation technique, and lowest with the meteorological order of elimination. According to the independent data check, the most representative method is the first technique, with the statistical order of elimination. The successive approximation technique apparently "over-analyzed" the data, resulting in relationships, particularly for stability index and wind direction, which fit only the particular set of data used in deriving the relationships.

Relationships Between Components of Suspended Particulate Matter and Meteorological Parameters

This section describes an attempt to relate the results of detailed chemical analyses made of a limited number of suspended particulate samples to meteorological conditions prevailing during the time samples were collected, and to deduce from the relationships some generalizations concerning possible sources of pollutants. The small number of particulate samples (36) in relation to the variability of meteorological conditions does not permit firm conclusions to be drawn; the conclusions reached are consistent with the data presented in this section, and with other relationships describing meteorological effects of air quality, some of which were shown in the preceding sections.

Total suspended particulate concentration values obtained by high volume sampling at station 1 during April 1956 were ranked and a selection of 36 samples was made, 12 each representing low, medium, and high total particulate concentrations. These selected samples were analyzed using an emission spectrograph for 17 metallic ions; the concentrations of these metallic ions, together with the total and organic particulate concentrations (Table 3-36), constitute the air sample data studied. One sample was lost in analysis.

All available meteorological data for each sampling period were examined to determine the conditions of air flow. A classification of each period was made, describing the direction from which the air came and the stability of the flow (Table 3-36).

Relative concentrations for each sample were obtained by dividing the concentrations of each constituent by the total concentration. As relatively simple measures of association between quantities, rank correlation coefficients were computed between concentrations (Table 3-37) and between relative concentrations (Table 3-38). In addition, average concentrations and relative average concentrations were computed for each of the three periods of the day, for groupings of sampling periods based on the direction of air flow, eliminating periods of mixed origin of the air, and for the three groupings of low, medium, and high total particulate concentrations (Table 3-39).

There are several factors which emerge with some degree of consistency from these analyses. No sectors were indicated as being free of sources of the substances measured, nor were any sectors indicated as being unique sources. Air flow from the direction of Rubbertown was always associated with relatively high concentrations of total particulate, and while concentrations of the individual constituents tended to be high, the relative concentrations were all low, indicating that the samples contained a higher proportion of material for which analysis had not been made.

Moderate to strong flow from the directions of least travel over the urban area to the sampling station (west-southwest through north-northwest) was generally associated with low concentrations of all constituents; concentrations of the organic portion was rather invariant, 5-10 $\mu g/m^3$, and concentrations of the metals tended to parallel concentration of total particulate. The low organic concentrations appear to represent a background concentration, probably of non-local origin, since the minimum concentrations of the organic portion for all sampling stations were about the same during the month, (e.g., two or three of the four stations in operation would show the same concentration, this concentration being near the minimum value for each station individually). The minimum organic concentration decreased during the month, while the concentrations of the associated metallic elements showed no consistent trend.

Flow from other urban sectors (north through south-southeast) showed generally higher concentrations of all elements, but with relative concentrations near or somewhat below average, except for a high relative concentration of the organic portion. These cases include some of the more quiescent periods.

The diurnal variations shown by these samples did not exactly correspond to those of the entire sampling record in the month considered, in that period two (0800-1600) showed a higher concentration of total particulate than did the month as a whole. The average organic concentrations for all three periods and the total particulate concentrations for the first and third periods were near the monthly averages. Concentrations of Mn, Fe, and Zn were at a maximum during the daytime periods, with the third period showing somewhat lower concentrations than the first period, in spite of the higher total particulate concentration in the third period. Pb showed the same type of diurnal variation, with reduced amplitude, as did the organic portion, with the maximum in the third period and the minimum in the second period.

It appears that there are four general types of pollution represented by the sampling results. One is emitted by sources throughout the urban area of and adjacent to Louisville. This pollution is relatively abundant in organic material, and relatively deficient in the metallic elements, except for Pb which occurs with near average relative concentrations. This "urban" mixture tends to be fractionated, with the inorganic portion settling out of the air, thus leaving a higher proportion of organic material in the air to be sampled. Concentrations of this type of pollution vary in an expected manner with meteorological conditions - that is, the more quiescent conditions usually thought of as leading to higher concentrations of pollution in urban areas were found to accompany high concentrations, with the concentration of all constituents, and particularly concentrations of the organic portion, decreasing with increased ventilation by the air flow.

The second type of pollution is found in association with flow from the general direction of Rubbertown. The principal difference between "Rubbertown" pollution and "urban" pollution is the inferred presence of appreciable amounts of additional substances not identified by the chemical analyses made. Some additional Fe, but not other metals, is also present in the "Rubbertown" pollution. Concentrations of "Rubbertown" pollution appear to be more or less independent of meteorological conditions, except, of course, for wind direction.

The third type of pollution seems to be material picked up from dry ground by stronger and gustier winds. This pollution is relatively abundant in all metals, including Ni, Bi, Ba, and Cd, and contains essentially no organic material. Concentrations of "dust" of this type show a rather poor relationship with concurrent meteorological conditions, although the relationship with sequences of meteorological conditions is consistent with the presumption that the immediate source is the ground surface. This "dust" on some occasions seemed to remain air-borne after the gusty winds that could raise dust had subsided, with concentrations falling gradually to low values. There is no way of discerning from these samples whether the "dust" was fallout from other urban areas that may have been redeposited any number of times before reaching the sampling location, or whether it was primarily soil particles.

The fourth type of pollution is the exotic organic component, which represents the minimum organic concentration to be expected at a given time over the area of the study. Estimates of the prior air mass trajectories associated with the periods of near minimum organic concentration at one or more stations were made. It was concluded that the "background" concentration is higher for air masses that passed over more northerly regions, and is higher the colder the air mass. Both factors are consistent with the relationship between organic concentrations and heating degree days indicated elsewhere in the findings. The minimum exotic organic concentration for the month considered (April) is estimated to have been about 4 $\mu g/m^3$. The average organic concentration for the 36 selected samples was 16.1 $\mu g/m^3$.

It appears that, as wind speed increases, an increasing amount of the total particulate material collected in samples is surface dust of unknown origin; concentrations of total particulate should therefore not be a particularly good index of atmospheric diffusion, since any relationship that might exist between meteorological conditions and concentrations of material transported directly from the sources would be obscured. For the same reason, a measure of only total particulate concentrations is not too good a measure of the influence of any given source or source area. Analyses of the samples to determine the composition of the total mass collected, together with analyses of the material emitted by the given source, are very helpful in determining the influence of the source in terms of the measure of pollution employed.

Summary of Findings Concerning Relationships Between Air Quality and Meteorological Parameters

The aerometric portion of the Louisville study sought to determine patterns of pollutants, both geographically and on a time scale, and to relate these findings to the sources of pollutants.

Consideration of air pollutant concentrations as a function of wind direction provided useful information on the contribution of given sources to points of reception. The emission and dispersion of pollutants act together in determining concentrations, and for a given receptor (sampling) location, wind direction takes into account both these factors, so that the effect of sources as a function of direction is provided by relationships of pollutant concentrations with wind direction alone.

Relationships between air quality and meteorological variables other than wind direction presented here represent, for the most part, limited analyses of selected data made for the purpose of establishing which meteorological variables or processes can be related to air quality parameters. The data shown are examples of the relationships that exist.

At all the West End sampling sites, periods of higher total particulate concentration were found to be associated predominantly with flow from the direction of Rubbertown. Winds from other directions were occasionally found to accompany high loadings, but generally were an infrequent occurrence. High loadings at station 3 were associated with flow from the urban area, including Rubbertown. At station 2, high loadings occurred principally with winds from the southeast quadrant, almost opposite to the direction of Rubbertown.

Periods of high organic fraction in the total particulate showed a more uniform wind direction effect. The whole of the Louisville area appeared to contribute to organic concentrations.

Wind speed effects on pollutant concentrations were found to depend on the type of pollutant, and therefore, on the character of the sources of pollutant. Organic particulate and soiling substances, which are produced in large part by ordinary urban living (home heating, automobiles, etc.), showed a pronounced and consistent inverse relationship with wind speed. Sulphur dioxide, which is produced by both home heating and industrial sources, showed a much weaker and more variable relationship with wind speed; stable periods in the summer months showed an increase of concentration with wind speed, whereas during the daytime, little relationship existed. Concentrations of total particulate showed essentially no relationship with wind speed at the West End sites, although a rather weak inverse relationship was found at the other two sites (stations 2 and 3). Periods of relatively high concentrations, particularly at the West End sites, were associated with both low and high wind speeds; it appeared that the inverse relationship with wind speed found for most sampling data was obscured by the pick-up of dust from the earth's surface by stronger winds.

The effect of temperature on pollution levels should be a reflection primarily of the dependence of emissions from space heating equipment on temperature. A pronounced annual variation of soiling substances and organic particulate was found, which roughly paralleled the annual variation of temperature. A similar but reduced annual variation was found in sulphur dioxide concentrations, and essentially no variation was found in total particulate concentrations. The greater part of the annual variations found are presumed to be due to variations of emission rates.

Rainfall was found to often precede or accompany periods of lower concentrations of all pollutants considered. No direct relationship could be found between total particulate concentrations and either the amount or duration of precipitation, however, it was therefore concluded that the occurrence of precipitation often accompanied periods of good atmospheric dilution, but the direct washout effect, at least for Louisville, is unimportant.

A pilot analysis of soiling index measurements was made, using multiple regression methods, for the purpose of describing the influence of each of several meteorological parameters, separately and jointly, on the pollutant measurements. Wind speed was found to be the most significant parameter, but its influence was very closely related to the influence of vertical stability in the atmosphere. The day-to-day effect of temperature was found to be very slight, but, because of the seasonal trends of both temperature and air quality, a weak inverse effect of temperature was found. Wind direction effect was significant, but erratic. An interesting side-light developed in the analysis, was that the most detailed analysis is not necessarily the best, for particularly with limited data, spurious relationships may be inferred.

Meteorological sequences appropriate to the periods when 36 selected high volume samples were collected were examined, together with detailed chemical analyses of the air samples. It appeared that the total particulate material collected might be considered as consisting of four general classes, according to origin. These classes were: (1) pollutants emitted by the whole of the Louisville area; (2) pollutants from Rubbertown; (3) surface dust, of either natural or urban origin; and (4) organic material from remote areas.

ODOR THRESHOLD DETERMINATIONS

In order to determine the frequency that odors were detectable in the ambient atmosphere by more nearly objective means, it was necessary to measure air concentration of odorous materials and to know the minimum concentration at which these materials were detectable by people. Odor thresholds were known for some materials but for others such data were not available. Thresholds were determined by observation of responses of a panel of people to specially prepared atmospheres containing known concentrations of odorant materials.

Although panelists varied significantly in odor sensitivity, each one seemed to maintain a fairly constant threshold for both the first and second determinations (Table 3-40). The panelists detected approximately 100 times lower levels of polychloroprene aqueous suspension (neoprene liquid latex), creosol, and styrene, than they did of acrylonitrile and gasoline.

A summary of odor threshold values for the five odorants determined in this study plus two additional ones for which information was previously available is given in Table 3-41. Graphically determined standard geometric deviations were remarkably close for all odorants, being 1.3 or 1.4. Since ideally a standard geometric deviation of one would indicate that all panelists had identical thresholds, the value of 1.3 or 1.4 seems to indicate a fairly low variation in threshold values among the panelists, and since the panelists were chosen to be a representative group of people, it is expected that similar results would be obtained if a larger group of the general population had been surveyed.

Uses of these data in the overall study are described elsewhere herein.

HUMAN RESPONSE TO AIR POLLUTION

The data gathered by the Trained Observer Corps gave some insight into human reaction as well as some information on the distribution, and occurrence of levels of pollution noticeable to people in West End Louisville. The data cannot be considered significant for most purposes because of inconsistencies in reporting practices of individual observers, differences in sensitivity to odors and irritation among people, and variation in opinions of observers as to what constituted presence or absence of phenomena reported. Degree of interest of observers in the project and in air pollution in general was also an important factor.

In general, the greatest number of positive reports for all categories of response (Table 3-42 and Figure 3-43) came from the west central section of the West End. A large number of positive reports were also received from areas near station 1 in the northern part of the West End. Reports of visible dustiness and eye, nose or throat irritation were concentrated mostly in western half of the West End. Odors were reported more widely, in agreement with the more general distribution of odor sources.

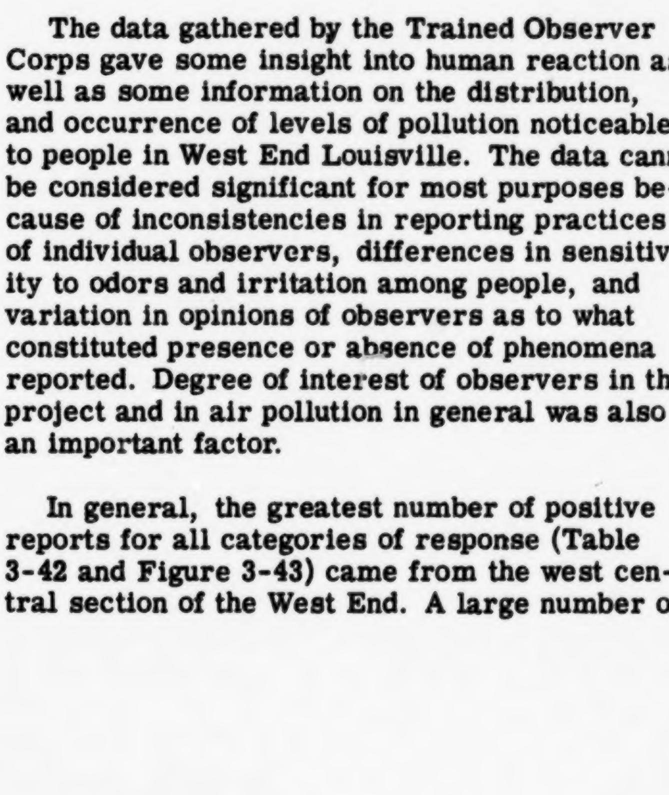

Figure 3-43. NUMBER OF DAYS ON WHICH OBSERVERS REPORTED VISIBLE DUSTINESS, IRRITATION, OR ODORS, NOVEMBER 1956 - MAY 1957 (212 DAY PERIOD)

The relationship between sulfur dioxide concentration and positive reports of odor and irritation was investigated. For this comparison only student reports for the period February 15 to May 31, 1957 were used. Reports were made on a two hour time basis (i. e., 0600-0800; 1600-1800; and 200-2200). Student observations from areas 14, 15, 16, 18, 19, 20, 22, 23, and 24 were selected, allowing comparison with the hourly sulfur dioxide peak values available from station B at 37th and Broadway, a location approximately in the center of this area.

The percentage of positive responses to odor or irritation when the peak sulfur dioxide concentration was less than 0. 1 ppm was compared with the percentage when the concentration was 0. 1 ppm or greater (Table 3-43). A greater percentage of positive odor responses was reported for concentrations above 0. 1 ppm for each of the three times of day observed, but due to the small sample size, the difference was not statistically significant. When all three periods were grouped together, the sample size was large enough to indicate that the difference was statistically significant.

Although the percent of positive irritation responses is slightly greater for sulfur dioxide peak concentrations equal or greater than 0. 1 ppm, this difference is not statistically significant.

About half of the positive responses were reported when the wind was blowing from Rubbertown toward the West End, but more than a third of the positive observations were made when the wind blew from non-Rubbertown directions.

To get an idea of which odors were noted most frequently, members of the Trained Observer Corps were asked at the end of the study to fill out an "opinion" questionnaire to augment their routine reports. The questionnaire asked them to list odors which they believed were "serious", and 54 percent listed sewer odors, 42 percent listed brewery odors, 36 percent listed "Rubbertown" odors, and 32 percent listed "coal smoke". Many other odors were classified as "serious" in the opinion of one or more of the observers.

The only firm conclusion that can be drawn from the reports of human response to air pollution are that people do notice air pollution and that an appreciable percentage of the population is subjected to an atmosphere which excites a sensory response on many occasions.

DUSTFALL MEASUREMENTS

Total Dustfall

The highest mean monthly dustfall recorded in Louisville in 1956 was 179 tons per square mile per month at the Bell's Lane location (No. 23) in Rubbertown (Figure 3-44 and Table 3-44). Values decreased rapidly from this point to about 40 at the southwestern boundary of the City of Louisville and to 20 at the northern edge of Louisville. The gradation from high to low dustfall demonstrates the importance of Rubbertown and other industrial sources of particulate matter at the southwest edge of Louisville.

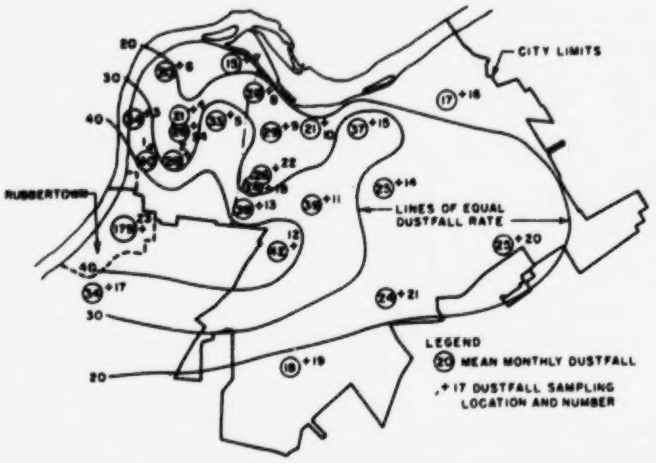

Figure 3-44. MEAN MONTHLY DUSTFALL IN LOUISVILLE; 1956 (TONS/SQ. MILE/30 DAYS - TOTAL WATER SOLUBLE AND INSOLUBLE)

Average dustfall for the sampling network as a whole varied considerably from month to month. The variation is not explainable in terms of heating or non-heating season (a factor influencing rate of particulate emissions) or precipitation (a factor influencing dustiness of the earth's surface). There was a slight trend toward higher dustfall with higher monthly average wind speed, reflecting the greater amount of wind-borne surface dust picked up by stronger winds.

Air-borne particulate concentrations and dustfall intensities demonstrated different patterns in western Louisville. Although at aerometric station 1 (Figure 2-1) concentrations of air-borne particulate matter were 25 percent greater than those for station 4, dustfall intensities near station 4 were approximately twice as great as those near station 1 (Figure 3-44). The higher dustfall at station 4 was probably due to coarse particulate emissions from Rubbertown sources, whereas, the higher concentrations of air-borne particulates at station 1 were probably due more to a summation of many sources of smaller particulates from the vicinity of the station, Rubbertown, and elsewhere.

Composition of Settled Dust

The source inventory indicates that Rubbertown industry number 8 releases large quantities of calcium compounds. The proportion of settled dust due to these emissions was demonstrated by X-ray diffraction analysis of dust collected on greased glass plates. The percent of calcium carbonate was related to the percent of silicon dioxide (quartz), a common constituent of soil (Table 3-45). Settled dust collected near Rubbertown was 60 percent calcium carbonate while that collected more than a mile from Rubbertown was only about 23 percent. The ratio of percent calcium carbonate to percent quartz in settled dust ranged from 2.1 at about one-half mile from Rubbertown to 0.34 at a distance of about 2.2 miles.

Summary

It is concluded that Rubbertown industries, and especially industry number 8 are responsible for a sizeable proportion of the dustfall in the vicinity of Rubbertown. A multitude of other sources not specifically identified in this study also contribute to the settled dust problem.

METAL DETERIORATION STUDY

Each set of stretched springs used in this study, one mounted inside and the other outside of an air sampling shelter, was exposed to the same ambient air temperature, relative humidity, and largely the same air pollutants. Springs on the outside of shelters were also exposed to precipitation, direct sunlight, greater dew formation, and air-borne particulates that were not drawn into the air sampling shelter (mostly large particles).

The springs inside the shelters showed little or no decrease in tensile strength during the study (Table 3-46). The springs outside the shelters at stations 1, 3, 4, 5, and 6 showed approximately five percent tensile strength decrease per month at a rate which was fairly uniform during the eight-month study. The spring outside the shelter at station 2 showed less decrease, approximately three percent per month.

The fact that springs exposed inside of shelters did not show a decrease in strength does not indicate that pollutants were not present but only that corrosion was not rapid enough to be detected by the method used. The more rapid corrosion of springs exposed outside of shelters is due to some combination of the effects of rain, dew, direct solar radiation, and pollutants to which springs inside shelters were not exposed. This study did not show the relative effect of these parameter.

The relatively slow corrosion rate of the spring at station 2 as compared to other stations could be due to lower concentrations of corrosive pollutants at station 2, difference in characteristics of springs used, or differences in rainfall, dew formation, or solar radiation. The data do not make it possible to determine just what was responsible.

BACTERIOLOGICAL STUDY

In this study three different measurements of bacterial concentration were obtained. Settling plant counts represent the number of bacteria-carrying particles settled or impinged on an agar surface; the slit sampler counts represent the number of bacteria-carrying particles in the ambient air; and the tangential-jet samples represent the total number of air-borne bacteria.

The three sampling devices were operated simultaneously and all samples were collected at a height of five feet above ground level. Total counts were made after 48 hours incubation at 37° C.

Sampling Period November 11-16, 1956

Counts of air-borne bacteria (Table 3-47) for the first three and one-half days of this period ranged from 1.8 to 13.4 bacteria-carrying particles settling per minute; from from 2.5 to 18.1 bacteria-carrying particles per cubic foot of air for slit samples; and from 65 to 371 bacteria per cubic foot of air for samples collected with the tangential jet sampler. Markedly lower counts were observed for samples collected on the final day and one-half. The results indicate that two population levels of air-borne bacteria existed during this five-day period. The reason for the lower counts in the latter part of the period is not definitely known. However, such factors as rain during the afternoon of November 15 and the resulting wet ground condition existing on the following day probably contributed.

Sampling Period February 11-15, 1957

Due to low air temperatures during this period, formation of ice in the liquid media of tangential jet samples necessitated discarding the majority of these samples. Satisfactory air temperatures for obtaining tangential jet samples existed on only two afternoons of the five-day period.

Settling plate counts during this period (Table 3-47) ranged from 0 to 7.2 bacteria-carrying particles per minute, with 63 percent of the samples having less than one. Counts with the slit sampler ranged from 0.1 to 12.7 bacterial-carrying particles per cubic foot of air. For the 16 tangential jet samples collected during the afternoons of February 12 and 13, the number of bacteria per cubic foot of air ranged from 1.0 to 49.2. Morning and afternoon mean counts on February 12 and 15 were decidedly higher than on the three other sampling days. No activities which could have been responsible for the higher levels were observed in close proximity to the sampling site. In general, the number of organisms collected by the settling plate and slit sampler indicated a low level of air-borne bacterial particulates present in the air during this five-day period.

Sampling Period May 13-17, 1957

For this period, the number of air-borne bacteria-carrying particles settling per minute on the open-plate samplers ranged from 0 to 7.8; slit sampler counts ranged from 0.4 to 16.0

bacteria-carrying particles per cubic foot of air; and the number of bacteria collected by tangential jet samples ranged from 1.0 to 188.9 per cubic foot of air (Table 3-47).

For the five-day period, mean counts for samples collected with settling plate and the slit sampler were within a comparatively narrow range. With the exception of the mean count of 134.3 for samples collected during the morning of May 14, this also was true for samples collected with the tangential jet sampler. The mean count of 134.3 bacteria per cubic foot of air was obtained during heavy rain showers. Contaminated rain water may have been collected by samplers and caused the high counts for some of the samples collected in the morning of May 14.

Sampling Period August 5-9, 1957

During August 5-9, settling plate counts ranged from 0.4 to 16.9 bacteria-carrying particles settling per minute; slit samples from 0.6 to 12.7 bacteria-carrying particle per cubic foot of air; and tangential jet counts from 3.4 to 292.0 bacteria per cubic foot of air. Plates exposed in the slit sampler usually contained a heavy growth of fungi colonies which probably inhibited growth of some bacteria. In addition, the aerial mycelium masked portions of the agar surface and interferred with counting. Due to these difficulties, counts obtained with the slit sampler are questionable and probably do not represent as high a number of bacteria as was actually present.

The counts obtained for the final two days are lower than those for the preceding three days. Air temperature was the only observed environmental condition which may have contributed to this reduction of air-borne bacteria. During August 5, 6, and 7, unseasonably low temperatures were present in the area. A gradual warming occurred during the three days and by August 8, normal summer temperatures prevailed. The higher temperatures August 8 and 9 may have had a detrimental effect on the viability of some bacteria and caused the reduction of air-borne bacterial concentrations.

Comparison of Four 5-Day Periods

Examination of the mean morning and afternoon counts obtained for the four 5-day periods (Table 3-47, Figure 3-45) reveals that the highest population of air-borne bacteria occurred during November. The low counts recorded on the afternoon of November 15 and for the entire day of November 16 were probably due to the meteorological and wet ground conditions mentioned above and may not be representative of typical levels of air-borne bacteria during that period. The lowest counts were observed during February, a cold weather month. In general, counts for August were slightly higher than those obtained during May. Counts for May may have been lower than usual due to wet ground conditions and precipitation. During August, unseasonably cool weather for the first three days may have been responsible for a higher count than would normally have been expected. For the final two sampling days, August 8 and 9, air temperatures were more typical of the season and counts were at a lower level. If such conditions had prevailed during the entire August sampling period, the level of air-borne bacteria would likely have been lower than for May.

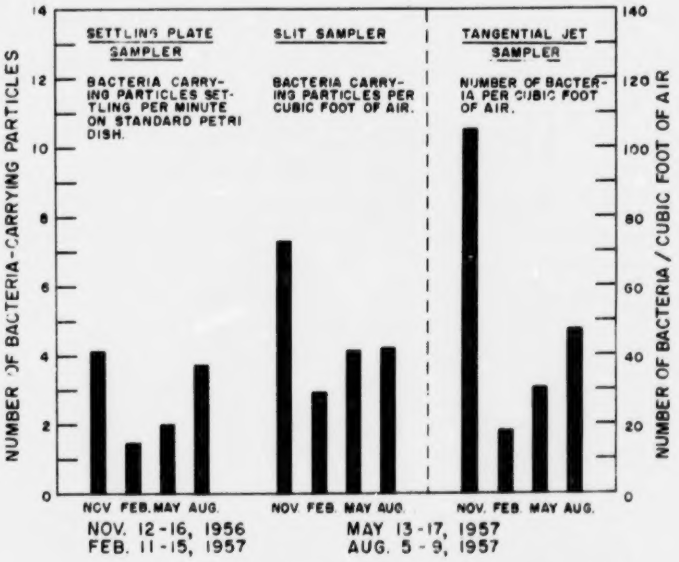

Figure 3-45. AIR-BORNE BACTERIA; STATION 5: NOV. 1956 - AUG. 1957

The bacteria counts obtained in this study with the settling plate, Casella slit, and tangential jet samplers indicate the levels of air-borne bacteria occuring in western Louisville. Since each of the four periods consisted of only five days duration, any extended effect of environmental conditions which may have influenced the level of air-borne bacteria was not observed. Only the possible effects of certain meteorological conditions encountered during the sampling period were considered.

POLLUTION REDUCTION

Particulate Emissions

Although much soot comes from domestic and commercial space heating units in West End Louisville, most of the fly-ash comes from industries in Rubbertown and surrounding area. Generation of power and other industrial use of coal are sources of emission of over 8000 tons of solids per year. Three of the four major users of coal (including two public utility power stations) reduce dust emissions to a near practicable minimum by use of high efficiency collection systems or use of non-dusty burning methods. Installation of high efficiency collectors on powerhouse stacks at Rubbertown industry number 3 would eliminate about 35 percent of the solids being discharged by industries from combustion operations.

One-third of all particulates emitted to the air in western Louisville arise from industrial processes at Rubbertown industry number 8. About a third of the particulates from this plant are discharged through wet type air cleaners into a high stack. Two-thirds of this plant's particulate emissions escape without treatment through roof openings, small stacks, doors, and other openings. The wet type collectors in use collect only a low percent of the particles five microns or less in size. Collectors of higher efficiency could be used to reduce the density of the plume from this plant's high stack. Planned installation of tap hole fume collection hoods and reduction of fine material in the charge could improve the emissions from Plant 8. A plant-wide air cleaning program has been instituted at a similar plant in another area.[38]

Emission of fine particulate matter from domestic and commercial use of coal may be reduced by use of low volatile coal in place of high volatile coal, and by use of combustion equipment and firing practices which prevent smoke or by changing fuel used to oil or gas.

Gaseous Emissions

Sulfur dioxide, the gaseous pollutant emitted in the largest quantity in western Louisville, is evolved mostly from industrial coal combustion but also from domestic and commercial use of coal. Gas cleaning methods have been used elsewhere (especially in Great Britain) to reduce emissions of this pollutant, but use of low sulfur coal instead of high sulfur coal is believed the most direct solution for reducing concentrations of this pollutant. Such low sulfur coal is available in eastern Kentucky.

Many of the industrial process gases liberated in Rubbertown contributed significantly to odor problems in the West End. Careful control of process operations and gas scrubbing can be used to reduce the frequency of odor episodes.

Large quantities of gasoline vapors are emitted from gasoline storage and handling at the storage depots (Plants 1, 10, 11, 12, 13) and the oil refinery (Plant number 5). Additional vapor recovery systems could be installed and other methods of preventing losses could be instituted to reduce these emissions. Such action often results in recovery of construction costs through gasoline savings over a few years time. A requirement that future tanks utilize floating roofs or other effective control methods would prevent this problem from growing.

Cresol and phenol arise by evaporation from treated railroad crossties stored in an outdoor yard. No feasible means for control of this problem is known except to store the crossties at a location where people will not be effected by emissions. This situation points up the necessity for close coordination between air pollution control officials, planning and zoning agencies, and industry.

A common source of pollution is the burning of leaves and refuse in backyards and at the curb. These practices not only release gaseous pollutants (including odors and irritants) but also cause haziness in the atmosphere. An adequate system for collection and disposal) of leaves and refuse would not only reduce the general load of air pollutants but also eliminate a fire hazard.

CHAPTER 4

RECOMMENDATIONS

In the light of the study results, the following actions are considered technically feasible for application in the study area and are recommended for consideration by the Air Pollution Control Board of Jefferson County:

1. To reduce the emission of solid particles produced by the burning of fuel: Strict adherence to a standard prohibiting the emission to the atmosphere of solids in excess of 0.85 pounds per 1,000 pounds of flue gas adjusted to 50 percent excess air for products of combustion. The Board should seriously consider lowering this figure in order to insure cleaner air.

   In addition, the Board should establish a maximum daily tonnage limitation on emission of solid particles from any one plant.

2. To reduce emission of solid particles produced by industrial process operations: A regulation that no industrial process plant shall from such process operations emit to the atmosphere more than one ton per day of solids.

3. To reduce the emission of irritant and corrosive gases produced by the burning of fuel: A regulation stipulating the maximum content of sulfur in fuel used.

4. To reduce the frequency of occurrence of odor episodes: A regulation that all industrial process plants, which emit odorous substances to the atmosphere be required to control such emissions to the extent necessary to prevent odor problems in the area surrounding the plant.

5. To reduce emission of hydrocarbon vapors from the evaporation of fuels: A regulation requiring floating roofs, vapor recovery systems or any other effective means to control emission of hydrocarbon vapors where petroleum products are processed, handled or stored.

6. Open burning of refuse and leaves should be prohibited.

7. The Air Pollution Control Board should expand its services to assure the proper implementation of regulations by the provisions of such field and laboratory equipment and personnel as are necessary to determine compliance. Early action in this regard would make most effective use of information accumulated during this study.

8. Steps should be taken to coordinate air pollution prevention and abatement activities for the entire metropolitan area including Louisville, Jeffersonville and New Albany. Close coordination between air pollution control agencies and zoning and planning commissions is a generally recognized "must" where the prevention of air pollution problems is to be effected. Failure to accomplish this is an invitation to poor selections in the locations of industries, and the creation of vexing air pollution problems which could and should be avoided.

9. The public should be kept informed regarding the purpose, objectives and activities of the air pollution control program, as well as the responsibility of all members of the community in the alleviation of air pollution. An educational program should be directed at the reduction of all types of air pollution. This should include information to residents and industries promoting the reduction of soot, odors and fly ash from fuel burning and the reduction of fumes and odors from the operation of automobiles, trucks and busses, the elimination of irritations, odors and dirt from domestic leaf and waste

burning, and the control of municipal sources of odors and air pollutants. City and county officials, residents, industrial, commercial and institutional management should all be made continuously aware of their respective responsibilities in protecting their air resources.

In addition to the above nine recommendations, (which are identical to those in the summary report, "The Air Over Louisville" 39/ the following recommendation is made:

10. To reduce particulate emissions largely smoke from domestic coal combustion: A regulation stipulating that only low volatile coal be marketed in Louisville for consumption in hand fired units.

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APPENDIX

Appendix A. MEMORANDUM OF AGREEMENT

Appendix B. DERIVATION OF ESTIMATING FACTORS FOR SOURCE STUDY

Appendix C. DETAILS OF METEOROLOGICAL STUDY METHODS, EQUIPMENT, AND INSTRUMENT LOCATIONS

Appendix D. DETAILS OF SOME ANALYTICAL PROCEDURES USED IN AIR POLLUTION ANALYSES

Appendix E. TABLES

APPENDIX A

MEMORANDUM OF AGREEMENT

MEMORANDUM OF AGREEMENT

BETWEEN

THE AIR POLLUTION CONTROL DISTRICT OF JEFFERSON COUNTY, LOUISVILLE-JEFFERSON COUNTY BOARD OF HEALTH, COMMONWEALTH OF KENTUCKY DEPARTMENT OF HEALTH, AND THE AIR POLLUTION CONTROL PROGRAM OF THE PUBLIC HEALTH SERVICE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

1. The above-named agencies will undertake a cooperative study of air pollution in Jefferson County, Kentucky, with the broad objective of augmenting existing knowledge on the nature, sources and extent of the problem as a basis for developing a rational program of control. The plan is essentially as follows:

Source Studies

The first two project proposals are aimed at the location and evaluation of specific sources of air pollution, and constitute the major effort proposed in the overall study.

Project I. Stack sampling and tracer studies and a revision of the effluent inventory for Louisville. This study will be confined primarily to the major industrial sources in the Rubbertown and other areas of Jefferson County. The objective of the study will be specifically to determine the nature and quantity of effluents from the sources in Rubbertown by stack sampling; to determine the range of their influence in the West End of Louisville by tracer studies; and to bring the effluent inventory up to date.

Project II. A study of odor sources by organoleptic methods using specially devised odor-measuring masks. This study will trace the more obvious odor sources and evaluate them.

Air Sampling and Analysis

The next two project proposals cover two different types of air sampling and analysis, and although ultimately aimed at the determination of air pollution sources, are one step further removed from the sources than the studies in the preceding group.

Project III. Continuous non-specific sampling of large air volumes with detailed and intensive analysis of selected samples by chemical spectroscopic, X-ray and electron diffraction methods. The samples will be taken on as continuing, round the clock, day after day basis as possible. However, only those samples will be analyzed which occur on days during which effects of air pollution, as indicated by competent observers, are more intense than usual, or days on which the meteorology of the area indicates a micro-meteorological pattern worth further analysis. Additional samples will be analyzed as controls. The analysis will involve as complete as possible a work-up using the mass spectrometer at the University of Louisville (if it is available in time for the project), X-ray diffraction equipment available at the Sanitary Engineering Center, and spectroscopic and spectrographic equipment available in both locations. The samples will be taken as freeze-out samples, compressed gas samples, or gas holder samples, for gas analysis: and as high volume filter paper, electrostatic or thermo-precipitator samples for particulate analysis.

The purpose of this project is to obtain as complete analysis of contaminants in the atmosphere of the West End of Louisville as possible during times when it adversely affects elements of the populace. The reason for taking samples on a basis as continuous as possible is that it is usually too late to start sampling when people have already noted that they are affected by the environment. To start sampling at that time may very well miss the cause of the adverse effect.

Project IV. Semi-mobile station for automatic recording devices. A trailer will be equipped with the principal automatic recording instruments presently available for air pollution measurement, such as recorders for ozone, oxides of nitrogen, carbon monoxide, and sulfur dioxide, and then run continuously at selected sampling sites. The results of these recorders will be analyzed and correlated with weather data.

The purpose of this project is to put to work as many as possible of the known methods for continuous air analysis which have been developed in air pollution studies in other areas, in order to compare the findings with those in other areas, and to seek to relate them to a solution of the Louisville problem.

2. The cooperating agencies' participation in the study will be substantially as set forth in the proposed budget submitted at the joint meeting of the cooperating agencies held in Louisville August 12, 1955.

3. The study will be under the technical direction of a representative of the Air Pollution Control Program of the Public Health Service. The person proposed for assignment for this purpose is Dr. August T. Rossano, Jr.

4. The four cooperating agencies will each designate a representative and an alternate to a Steering Committee for the project. The Technical Director of the project will act as Executive Secretary for the Steering Committee, and shall arrange for meetings of the Steering Committee on at least a monthly basis. The Steering Committee shall be concerned primarily with administrative matters, leaving the technical direction of the study to the Technical Director.

5. The Technical Director shall present a monthly progress report to both the Steering Committee and the Air Pollution Control District of Jefferson County.

6. The Technical Director shall be responsible for recommending the recruitment, selection and separation of personnel employed for the study. The Air Pollution Control District of Jefferson County shall be responsible for the appointment and employment of such personnel.

7. Equipment and supplies, other than those to be furnished by the U. S. Public Health Service, shall be purchased by the Air Pollution Control District of Jefferson County, on recommendation of the Technical Director, provided the cost of such equipment and supplies comes within the budget of the proposed plan.

8. Release of information for publication or to the press shall be only by unanimous approval of the Steering Committee, and such release shall be through the Air Pollution Control District of Jefferson County and subject to its approval.

9. The final reports of the study shall be issued jointly by the cooperating agencies and subject to the approval of each of the agencies.

10. The Technical Director shall be responsible for the preparation of all reports.

APPENDIX B

DERIVATION OF ESTIMATING FACTORS FOR SOURCE STUDY

VAPOR LOSSES FROM FIXED ROOF STORAGE TANKS

Breathing Losses

The basic theory of vapor losses from fixed roof tanks has been developed.[40] The maximum volume lost in venting of such tanks is determined by tank dimensions, vapor space temperatures, vent pressures, and liquid vapor pressures as follows (See list of symbols at end of discussion.

$$V_V = V_2 - V_1 = \left(\frac{A + G_1 - p_1}{A + G_2 - p_2}\right)\left(\frac{T_2}{T_1}\right)\left(V_1\right) - V_1 = (T.E.)\ V_1 \quad (B-1)$$

The total breathing loss in pounds is therefore:

$$R_T = NL_V = NV_V \times \frac{P_V}{P} \times \frac{M}{379} \times \frac{460}{T} \times \frac{P}{14.7} \quad (B-2)$$

The evaluation of N, the number of ventings per unit time, and p_V, the average vapor pressure of the liquid in the vapor space, are more difficult. The American Petroleum Institute (API) has determined empirically average vapor loss for storage in tanks 40 feet high, half full of a liquid with a vapor pressure of 5 psi. at 60 degrees F. The equation applies to average U. S. A. climatic conditions with an annual average diurnal temperature change of 16 degress F. Expressing their equation in terms of pounds:

$$B_E = 7.2\ F_o F_p D^{1.8} \quad (B-3)$$

In this equation the variability of p_V is taken into account by the use of an empirically determined factor which is a function of b, the tank voidage (in their work F_o is expressed as a function of tank outage). Their data are replotted as a function of b in Figure B-1. This factor relates the degree of saturation and uniformity of mixing to conditions with a tank half

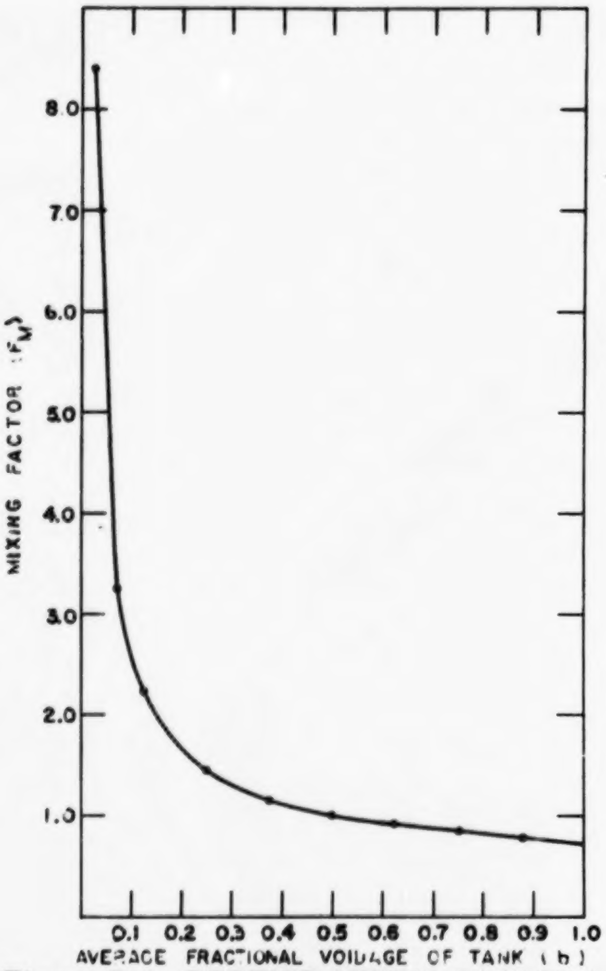

Figure B-1. DERIVED MIXING FACTOR FOR ESTIMATION OF DEGREE OF UNIFORMITY OF VAPORS LOST FROM TANKS BY "BREATHING" F_M = 1.00 AT b = 0.5

full. Thus, for example, for a tank 80 per cent full ($b = 0.2$) the effective vapor pressure in the vapor space is 1.7 times that with the tank half full. Because of several other variables inherent in the API constant and since only one variable (D) was considered by them, the true vapor pressure in the vapor space cannot be determined directly. Consequently the use of F_m is contingent on the use of another empirical factor.

This factor may be combined with the factor relating N to D. Using the API equation and the theoretical development:

$$N = K \; F_k \; F_p \; D^{-0.2} \qquad \text{(B-4)}$$

where F_k is a function of b. F_m (Figure B-1) can be shown to be:

$$F_m = F_k \; K_s \qquad \text{(B-5)}$$

where $K_s = pv/p$. Therefore the theoretical breathing loss equation is, in semi-empirical form:

$$B_{SE} = \left[KF_nF_pD^{-0.2} \right] \left[(T.E.)\,(V_1) \right]$$

$$\left[\frac{K_sP}{P} \times \frac{M}{379} \times \frac{460}{T} \times \frac{P}{14.7} \right] \qquad \text{(B-6)}$$

$$\text{or } B_{SE} = KF_mF_pD^{-0.2}$$

$$V_1 \left[T.E. \right] \times \frac{p}{p} \times \frac{M}{379} \times \frac{460}{T} \times \frac{P}{14.7} \qquad \text{(B-7)}$$

F_p is the so-called "paint factor" which relates the degree of heat absorption of the tank surface to its color (Table B-1 in Appendix E). The heat absorption of an aluminum tank is arbitrarily chosen as 1.0.

Using the data of the API, K has a value of 179. The working formula is therefore:

$$B = 14.8 \; F_mF_pD^{-0.2} \; V_1\left[T.E.\right] \; p \, MT^{-1.0} \qquad \text{(B-8}$$

The temperature effect factor required the knowledge of minimum and maximum liquid surface and vapor space temperature. The temperatures in Table B-2 were calculated from API data using $t_1 = t - 5°$ F.; $t_2 = t + 5°$ F.; $T_1 = t - 10°$ F; and $T_2 = t + 45°$ F.

For the Louisville study mid-continent temperatures were used.

Filling Losses

According to API estimates 40/ the filling loss, that is, physical displacement of vapors in the unfilled tank volume, can be estimated for petroleum storage (in pounds) by use of the formula:

$$F = 0.0005 \; pV_fK_f$$

where K_f is a factor relating per cent saturation of the vapor space with tank turnovers per year (Figure B-2). A more general equation developed from theoretical considerations is:

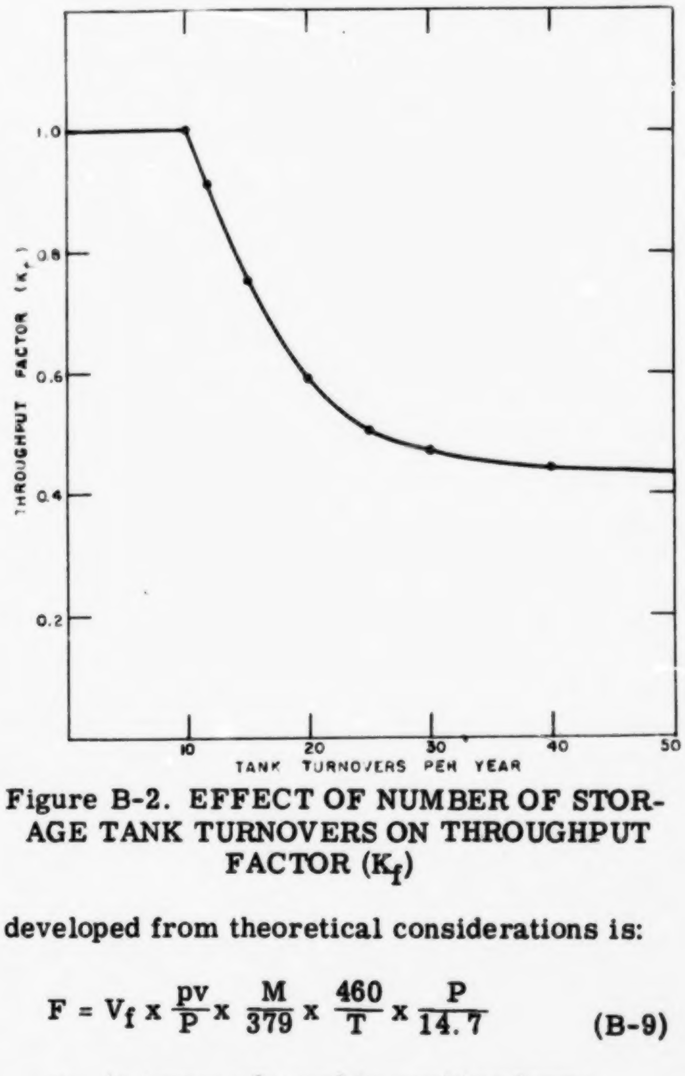

Figure B-2. EFFECT OF NUMBER OF STORAGE TANK TURNOVERS ON THROUGHPUT FACTOR (K_f)

$$F = V_f \times \frac{pv}{P} \times \frac{M}{379} \times \frac{460}{T} \times \frac{P}{14.7} \qquad \text{(B-9)}$$

or, in terms of p and in working form:

$$F = 0.083 \; K_f \; p \; V_f \; MT^{-1.0} \qquad \text{(B-10)}$$

Boiling Losses

The tendency of a stored liquid to experience boiling depends upon its volatility and its maximum temperature. The boiling loss problem, therefore is limited largely to refineries and other locations which handle natural gasoline blending stocks, and other highly volatile liquids.

In calculating the temperature effect factor for certain storage tanks in the Rubbertown area used to store high volatile materials, it was noted that the total vapor pressure of the stored liquid in the vapor space exceeded the vent pressure plus atmospheric pressure. In other words the vent must open and surface boiling occur. A method for estimating this boiling loss was developed.

In most cases where highly volatile liquids are stored in low pressure tanks the bulk of the liquid is kept at low temperature. To determine average surface temperature in this case the average value of $t - t_L$ was determined. For Louisville using Weather Bureau data and the temperatures of Table B-2, $t - t_L$ has an annual average of 55 degrees F.; i. e. the average liquid surface temperature is 55 degrees F. greater than the bulk liquid temperature (taken as equal to annual average air temperature). Thus for any value of t_L, t was calculated; t_1, t_2, T_1 and T_2 being calculated from t.

A heat balance on the storage tank was made by computing the heat transferred to the liquid surface by radiation and assuming this heat is used as latent heat for liquid vaporization. (No sensible heat computation is necessary since, prior to the vent opening, this is added as in the normal breathing loss.) Although the vent must open and close as boiling lowers the temperature of the liquid surface, the loss was computed on a continuous basis using the liquid surface boiling point (t_B) as a total pressure of $A + G_2$. This temperature is less than that calculated by the method outlined above indicating conservative loss estimates.

The heat radiated to the liquid surface was calculated using Hottel's method[41].

$$q_{net} = 0.173\, A_1 d \left[\left(\frac{T_B}{100}\right)^4 - \left(\frac{T}{100}\right)^4 \right] \quad \text{(B-11)}$$

The temperature of the radiating surface was taken as the average vapor space temperature calculated from t_B using the API factors[40]. This assumes the tank metal surrounding the vapor space has the same temperature as the average vapor space temperature, which is realistic. The emissivity d was calculated (for an enclosed surface) from the formula[41]:

$$d = \frac{1}{1 + \left(\frac{1}{E_1} - 1\right) + \frac{A_1}{A_2}\left(\frac{1}{E_2} - 1\right)} \quad \text{(B-12)}$$

The emissivities used were $E_1 = 0.95$ (liquid surface assumed similar to water) and $E_2 = 0.80$ (tank shell assumed to be steel). The areas A_1 and A_2 are the liquid surface area and the tank shell area surrounding the vapor space, respectively.

The calculation of boiling loss was then made using:

$$L = 26{,}000 \times \frac{q_{net}}{H} \times M \quad \text{(B-13)}$$

Stored Liquid Mixtures

To estimate breathing loss from stored liquid mixtures Raoult's Law was assumed to hold. Therefore:

$$B_n = 14.8\, F_m F_p D^{-0.2}\, V_1\, (T.E.)\, x_n p_n M_n T^{-1.0} \quad \text{(B-14)}$$

In determining (T. E.), the total pressure $p = x_a p_a + x_b p_b + \ldots$ was used at minimum and maximum liquid surface temperatures.

Filling loss for liquid mixtures was estimated using Raoult's Law. Therefore:

$$F_n = 0.083\, K_f\, x_n\, p_n\, V_f\, M_n T^{-1.0} \quad \text{(B-15)}$$

Boiling loss for liquid mixtures involves a more complicated method. In all cases of boiling, the storage tank throughput is much greater than the loss by boiling. Consequently the liquid composition can be assumed to remain constant, in which case the boiling point of the mixture remains constant. The latent heat of vaporization of the mixture, H_m, is the latent heat of a mixture with the vapor composition at the boiling point. This composition is determined by the formulae:

$$y_a = \frac{x_a p_a}{x_a p_a + x_b p_b + \ldots} = \frac{x_a p_a}{p} = \frac{x_a p_a}{A + G_2} \quad \text{(B-16)}$$

$$y_b = \frac{x_b p_b}{A + G_2}, \text{ etc.} \quad \text{(B-17)}$$

The latent heat of the mixture, H_m, is:

$$H_m = y_a H_a + y_b H_b + \dots \qquad \text{(B-18)}$$

The latent heat of the invividual components, H_n, was determined at the boiling point using the Kistiakowsky[42] and Watson[43] equations. The boiling loss of each component was then calculated by:

$$L_n = 26,200 \left(\frac{q_{net}}{H_m}\right) y_n \; M_n \qquad \text{(B-19)}$$

VAPOR LOSSES FROM OTHER THAN FIXED ROOF TANKS

For other than fixed roof tanks the factors developed by the API were used (Table B-3).

LIST OF SYMBOLS USED IN STORAGE TANK LOSS EQUATIONS

p, p_1, p_2 = stored liquid vapor pressure at t_L, t_1, and t_2 respectively, psia.

p_n, p_a, p_b = component liquid vapor pressures at t_L or t_B, psia

p_v = average vapor pressure in the vapor space = $F_s p$, psia

q_{net} = net loss of energy by radiation of body at T_B in surroundings at T, Btu/hr.

t, t_1, t_2, = average, minimum, and maximum liquid surface temperatures, degrees F.

t_L = average bulk liquid storage temperature, degrees F.

t_B = boiling point of liquid surface, degrees F.

x_n, x_a, x_b = component liquid mole fractions, dimensionless

y_n, y_a, y_b = component vapor mole fractions, dimensionless

A = atmospheric pressure = 14.7 psia

A_1 = area of liquid surface, sq. ft.

A_2 = area of tank shell surrounding vapor space, sq. ft.

B = breathing loss from tank, by expansion, pounds/yr.

B_T, B_E, B_{SE} = theoretical, empirical, and semi-empirical forms of B, pounds/yr.

B_n = breathing loss of liquid component, pounds/yr.

C = tank capacity, cu. ft.

D = diameter of tank, feet

F = filling loss from tank, by displacement, pounds/yr.

F_k = empirical factor relating N to D, = F(b)

F_m = mixing factor = $K_k K_s$

F_n = filling loss of component, pounds/yr.

F_o = outage factor as used by API, empirical

F_p = paint factor = f (color), empirical

G_1 = tank pressure at which vacuum vent opens, psig

G_2 = tank pressure at which pressure vent opens, psig

K = empirical constant relating N to D

K_f = throughput factor, see Figure B-2, dimensionless

K_s = saturation factor = $\frac{P_v}{P}$, dimensionless

L = boiling loss, by radiational liquid surface heating, pounds/yr.

L_n = component boiling loss, pounds/yr.

L_v = weight of vapor lost in each venting, pounds

M = molecular weight of vapor, pounds/pound-mol

M_n = molecular weight of component, pounds/pound-mol

N = number of ventings per year, $(\text{years})^{-1}$

P = total pressure in vapor space at time of loss, psia

T, T_1, T_2 = average, minimum, and maximum absolute vapor space temperatures, degrees R

T_B = absolute boiling point of liquid surface, degrees R

V_1, V_2 = minimum, and maximum vapor space volumes, cu. ft.

V_f = tank throughput volume, cu. ft./yr.

V_v = volume of vapor lost in each venting = $V_2 - V_1$, cu. ft.

[T. E.] = temperature effect = fractional vapor volume expansion:

$$\left[\left(\frac{A+G_1-p_1}{A+G_2-p_2}\right) \left(\frac{T_2}{T_1}\right) - 1 \right]; \quad \text{dimensionless}$$

E_1, E_2 = emissivities of liquid surface and tank shell, dimensionless

b = fractional voidage of tank = unfilled fraction, dimensionless

d = factor allowing for non-black surfaces (see text), dimensionless

H = latent heat of vaporization of liquid at its boiling point, Btu/pound-mol

H_m = latent heat of vapor mixture, Btu/pound-mol

H_n = latent heat of component, Btu/pound-mol

EVAPORATION FROM OPEN BASINS

For plane surfaces located parallel to the direction of air flow, and in the turbulent region [8]

$$j_M = 0.036\ Re^{-0.2} \qquad \text{(B-20)}$$

(see nomenclature below). k_G is calculated from this relationship by:

$$j_M = \frac{k_G}{G_M}\ (Sc)^{\frac{2}{3}} \qquad \text{(B-21)}$$

where G_M is calculated from wind speed and Sc = $(u/\rho D)$ is obtained from Tables[44]. For example, for a methanol-water mixture stored in a 225 foot basin in Louisville (avg. wind speed = 8.5 mph), k_G = 0.154. The amount of component A (e.g. methanol) diffusing per unit time is:

$$N_A = k_G\ (y - y_i) \qquad \text{(B-22)}$$

For evaporation into open air, y may be assumed equal to zero. The mole fraction of A in the interfacial gas is determined from Raoult's Law. The mole fraction of A in the liquid mixture is determined from process data. For example, for 17,000 pounds of methanol discharged per day into a stream of 40,000 gpm of river water, the mole fraction of A (methanol) in the liquid mixture is 2.0×10^{-5}. This produces a y_i of 2.4×10^{-6} at the mean annual Louisville temperature about (60 degrees F.). The total annual loss of component a (methanol) is therefore 2.04 tons for a 225 foot basin.

As a check on the general applicability of this method, Weather Bureau data for water evaporation from open surfaces were consulted. These data show an average annual loss into still air of approximately 4.0 inches per month. The theoretical loss into an 8.5 mph wind is 7.2 inches per month. This is considered good agreement since the mass transfer coefficient increases with increasing velocity.

Nomenclature

j_M = mass transfer factor, $(k_G/G_M)(\mu/\rho D)^{2/3}$, dimensionless

k_G = mass transfer coefficient, lb.-moles/(hr.) (sq. ft.) (mole fraction)

y = mole fraction of component A in bulk of gas, dimensionless

y_i = mole fraction of component A in gas at interface, dimensionless

D = diffusion coefficient, sq. ft./hr.

G_M = molar mass velocity, lb.-moles/(hr.) (sq. ft.)

N_A = lb.-moles of component A diffusing/(hr.) (sq. ft.)

Re = Reynolds number, $\frac{dV^{\rho}}{V\mu}$, dimensionless

Sc = Schmidt number, $\frac{\mu}{\rho D}$, dimensionless

V = average wind speed, ft./hr.

μ = viscosity, lb. mass/(ft.)(hr.)

ρ = density, lb./cu. ft.

EMISSIONS FROM COMBUSTION OPERATIONS

Gases From Industrial Coal Combustion

Sulfur dioxide and sulfur trioxide. Since the sulfur content of fuels is variable, the estimating factor is best expressed in terms of the sulfur content, S, in lbs. of sulfur per pound of fuel. An estimate such as made by Wohlers[45], i.e. 0.020 lbs. SO_2 per lb. coal, does not consider this variation. In terms of the sulfur in the fuel burned to sulfur oxides, various estimates have been made ranging from 90 percent[46] to 100 percent.[47] An average value of 95 percent was chosen, which agrees with experimental work by Crumley and Fletcher.[48] Others have shown that for all solid, liquid, and gaseous fuels burned industrially, the ratio of SO_2 to SO_3 remains close to 10:1 by volume.[49] Using this ratio and assuming 95 percent of the sulfur is burned to the oxides, the estimating factors were calculated:

SO_2 = 1.73S lbs. SO_2 per lb. coal fired (B-23)

SO_3 = 0.21S lbs. SO_3 per lb. coal fired (B-24)

Oxides of nitrogen. The production of nitrogen oxides by high temperature oxidation of atmospheric nitrogen occurs in industrial coal burning. Unfortunately no experimental work has been yet reported on typical effluent concentrations. An estimate of these oxides have been made[45] but this is based on the combustion of fuels other than coal. Orning[50] has presented some data based on the theoretical thermodynamic considerations of Myers, et al.[51] These data have direct application to the problem of nitrogen oxides production specifically from coal burning. If a temperature of 2000 degrees F. is assumed to occur in the fire box an equilibrium concentration of 700 ppm NO_2 will exist in the flue gas at 50 percent excess air. Orning assumes that equilibrium may be maintained at this level by rapid gas cooling. Using Orning's data and a flue gas volume of 180 cu. ft. (STP) per lb. coal (50 percent excess air, coal of 70 percent carbon), this concentration is equivalent to 0.016 lbs. NO_2 per lb. coal fired. A similar calculation for 20 percent excess air (equilibrium NO_2 concentration = 500 ppm at 2000 degrees F.) shows an oxides of nitrogen production of 0.0086 lbs. NO_2 per lb. coal fired. Since most industrial coal burning facilities operate in this excess air range an intermediate value is probably applicable. Considering that fire box temperatures may be lower than 2000 degrees F. at excess air quantities greater than 20 percent the average was weighted in favor of the lower concentration:

Oxides of nitrogen (as NO_2) = 0.010 lbs. NO_2 per lb. coal fired (B-25)

This value, incidentally, agrees fairly well with factors determined experimentally for the combustion of gaseous and liquid fuels (see elsewhere in this appendix).

Inorganic chlorides. Chlorides are emitted in small quantities from coal combustion processes, probably in the form of hydrogen chloride gas. Measurements of flue gas concentrations from coal burning operations have not been made. An estimate of the magnitude of this emission has been made by Meetham[47], based on the average chlorine content of coal. He estimated 0.002 lbs. HCl per lb. coal fired. Information from the Coal Manual for Industry[52] indicates a chloride emission (as NH_4Cl) of 3.55 lbs. per ton coal fired per 0.1 percent Cl. This is equivalent to 0.0023 lbs. HCl per lb. coal fired for a 0.2 percent Cl coal. The chlorine content of coal is variable and frequently is not reported in coal analyses. A United States variation of 0.1 to 1.0 percent with an average of about 0.2 percent is reported.[52] On the basis of the above data an approximate factor for chloride emission was used:

Inorganic chlorides (as HCl) = 0.002 lbs. per lb. coal fired (B-26)

Fluorides. Fluorides also must be estimated on the basis of coal composition since effluent analyses are not available. An approximate average fluorine content is 0.02 percent by weight.[47] This content will produce an emission rate, (assuming 100 percent liberation) as follows:

Fluorides (as HF) = 0.0002 lbs. per lb. coal fired (B-27)

Other gaseous products. Other pollutant gaseous products of combustion are probably emitted in coal burning operations. In the combustion of fuel oil and gas, effluent analyses show the presence of significant quantities of aldehydes, organic acids, ammonia, and even hydrogen cyanide. These compounds are formed through incomplete combustion of initial distillation products or by gaseous phase chemical reactions at high temperatures. Reliable estimates of the magnitude of such emissions cannot be made for coal burning either on the basis of thermodynamic considerations or by the use of fuel analyses. It would not be valid and could possibly be highly erroneous to use estimates based on the combustion of other fuels, as has been suggested.45/ Estimation of these other gases will require experimental work.

Solids From Industrial Coal Combustion

Coal is fired by several methods in industrial plants. Nearly all such methods are characterized by high combustion efficiency. Consequently the production of carbonaceous and tarry particulate matter ("smoke") is, with one exception, insignificant except under certain short duration operating conditions. On the other hand, industrial coal firing operations are characterized by comparatively high gas velocities through the fuel bed and in the stack. This fact together with the use of fine or pulverized coal results in the entrainment of large quantities of the ash residue. This residue is composed of SiO_2, Al_2O_3, carbon, Fe_2O_3, and other oxides.53/ The amount of ash entrained and subsequently discharged as "fly ash" can vary widely depending on the firing method and coal being burned. A review of the literature indicates that the ash emission can be conveniently expressed in terms of A, the ash content of the fuel as lbs. ash per lb. fuel

Underfeed stokers. Estimates of ash emission from use of this firing method vary. In terms of lbs. ash emitted per lb. coal fired, Swengel54/ suggests 0.10 A; Kaiser55/ lists <0.15A; Marks and Kaiser56/ present data showing 1/3 lbs. dust per 1000 lbs. flue gas (at 50 percent excess air) which can be converted to approximately 0.19 A; Miller's data57/ can be similarly converted to 0.45 A. The last estimate is probably high. The following approximate average value was used:

Solids (ash) = 0.15 A lbs. per lb. coal fired (B-27A)

Traveling grate stokers. Ash emission estimates for this firing procedure are more uniform, 0.15 A, 0.15A and (by calculation) 0.09 A (References 54, 55, and 56 respectively). The most common estimate was used:

Solids (ash) = 0.15 A lbs. per lb. coal fired (B-28)

Cyclone furnace. This firing method is used in a comparatively small number of installations. Only one value for ash emission from this firing method was found:54/

Solids (ash) = 0.15 A lbs. per lb. coal fired (B-29)

Pulverized coal burning. A large quantity of the ash content of the coal is discharged in this firing method because of the technique of burning the coal in a suspended state. Among estimates which have been made are 0.75 A and >0.50 A (References 54 and 55 respectively). The former is considered more accurate and was used:

Solids (ash) = 0.75 A lbs. per lb. coal fired (B-30)

Spreader stokers. This firing method is quite popular in this country and in England where it is called "sprinkler" firing. The use of estimating factors here is complicated by variations in firing methods as use of overfire jets and dust reinjection. A further complication arises since, contrary to most mechanical firing methods used, industrial spreader stoker firing is often characterized by the emission of unburned carbon as well as ash. Consequently, reinjection of collected flue gas solids or injection of overfire air is sometimes used to improve combustion efficiency. General estimates of total solids emission have been made in terms of ash content. The following estimates do not take into account dust reinjection or overfire jet operations: total solids = 0.50 A (as ash 0.30 A, as carbon 0.20 A)54/; total solids = 0.4 A to 0.8A (as ash 0.2 A to 0.4 A, as carbon 0.2 A to 0.4 A)55/; total solids = 0.47 A (by calculation); total solids = 0.62 A (by calculation) (References 56 and 57 respectively). The concensus indicates a general average of total solids = 0.6 A, which is about half ash and half carbon. It should be noted that this carbon is not the carbonaceous material of which coal "smoke" is usually considered to be composed. Rather, it is unburned fuel particles, as opposed to condensed or cracked hydrocarbon gases.

One team of investigators[58] has studied the effects of dust reinjection and the use of overfire jets in relation to total solids emission from spreader stoker operations. The combinations of reinjection with and without overfire jets, and vice versa, were studied, the results being expressed in terms of dust loading in the furnace breeching. These data, when converted to lbs. of total solids per lb. coal fired, showed emission rates given in Table B-4.

The weight of total solids emitted has been expressed in terms of ash content by the use of the ash content of the fuel fired and assuming 60 percent of the dust loading at the breeching eventually escapes into the atmosphere.[56] Examination of these data shows that the only important variable is dust reinjection, i. e. when expressed in terms of ash content total solids emitted are approximately 0. 6 A without dust reinjection and 1. 0 A with reinjection. The former figure agrees well with the consensus of other investigators (see above). With dust reinjection, however, total solids discharge increased. This is due to the recycling of collected particles containing carbon which are then reburned yielding smaller sizes of ash which can be carried out with the flue gas.

On the basis of these data the following estimates were chosen for spreader stoker operation:

Without Dust Reinjection

Total Solids (ash and unburned carbon) = 0. 6 A lbs. per lb. coal fired. (B-31)

With Dust Reinjection

Total Solids (ash and unburned carbon) = 1. 0 A lbs. per lb. coal fired. (B-32)

Particle size. Kaiser[55] has presented in a general summary form typical size frequency analyses of emitted solids from various industrial coal firing methods. The size frequency distributions, when plotted on log-probability paper, yield straight line approximations. Consequently, these data may be expressed in terms of two variables, mass median diameter (geometric mean) and the standard geometric deviation (Table B-5). Using one micron as an arbitrary dividing point between coarse and fine solids, it can be seen that fines production is distinctly related to firing method. Cyclone furnaces produce the greatest proportion of fines and traveling grates, the least. These data apply to the size distribution without dust collection equipment. Estimates of size distribution of effluents from dust collectors must be based on data such as the above and collector performance.

Gases From Domestic and Commercial Coal Combustion

Sulfur dioxide, sulfur trioxide, and hydrogen sulfide. Sulfur oxides production in domestic and commercial coal burning operations is slightly different than in industrial combustion operations. This is due primarily to lower fuel bed temperatures, and often, incomplete combustion. A survey of sulfur gas production in domestic furnaces was made years ago.[59] It showed that approximately 90 percent of the sulfur in the coal was liberated to the atmosphere during combustion. Recent tests[48] show that this is predominantly as SO_2, with about 1. 5 percent of the sulfur liberated in the form of SO_3 and 0. 4 percent as H_2S. These data when converted to estimating factors in terms of S, the sulfur content, yield the following formulas that were used:

SO_2 = 1. 8 S lbs. per lb. coal fired (B-33)

SO_3 = 0. 04 S lbs. per lb. coal fired (B-34)

H_2S = 0. 004 S lbs. per lb. coal fired (B-35)

Oxides of nitrogen. Nitrogen oxides production in combustion operations is affected by temperature. The difference between production of these oxides in industrial and domestic and commercial installations is therefore significant. In recent tests[48] equilibrium nitrogen oxides concentrations of 0. 9 ppm in the flue gas were measured. Using the gas volume and fuel consumption data of these tests, total oxides of nitrogen production when expressed in terms of fuel weight yield the following factor:

Oxides of nitrogen (as NO_2) = 0. 0002 lbs. per lb. coal fired (B-36)

Total hydrocarbons. Undoubtedly, more total hydrocarbons are produced in efficient combustion. These, however, partially condense, are cracked, or polymerize to form solids such as carbon chains and tarry hydrocarbons. Estimates of these solids are presented elsewhere in the appendix. In the absence of data to the contrary the estimate used for gaseous hydrocarbons was taken as:[48, 60]

Total hydrocarbons = 0.010 lbs. per lb. coal fired (B-36A)

Halides. These were estimated on the basis of coal composition as in the case of industrial coal burning. The same estimating factors were chosen.

Other gaseous products. As in the case of industrial coal combustion, other gaseous pollutants, besides those listed above, are probably emitted during domestic firing. Reliable estimates are not possible because of the lack of quantitative effluent analyses.

Solids From Domestic And Commercial Coal Combustion

Coal is fired in domestic and commercial furnaces and stoves both by mechanical stokers and by hand. Since domestic and commercial coal smoke has been a problem for many years, studies of solids emission from such fires were started many years ago. It was unfortunate in one respect, however, when the use of the Ringelmann Chart became widespread around the turn of the century since smoke measurements were then, and still are, made on the basis of an optical property of smoke rather than its weight. Consequently, a very thorough literature search was required to find even approximate estimating factors for total solids emissions.

Hand-fired furnaces. Comprehensive tests of hand-fired low pressure steam plants were made in Chicago years ago.[59] The results of these tests (from stack samples) indicate that 1.2 percent of the fuel weight is emitted as solids. In spite of the comparatively long time since these tests were made they are probably still representative of hand-fired operations. More recent surveys by *Coal-Heat* magazine and the Coal Producers' Committee for Smoke Abatement, have shown that most hand-fired low pressure plants are still operated inefficiently and are of extremely old design.[61, 62, 63] The only other reported tests of emissions from hand-fired furnaces made in this country (on a weight basis) indicate that over the life of the fire 5.7 percent of the fuel weight becomes air-borne at the surface of the fuel bed.[64] Most of these particulates are burned while suspended above the bed.

Studies have been made[65, 66] to determine the proportion of ash escaping from hand-fired coal-burning furnaces by means of material balances. Average values of ash emitted vary from 2.4 to 5.5 percent of the ash in the coal. Expressing these in terms of fuel weight, ash emission averages about 0.2 percent of the fuel fired. Using the 1.2 percent figure above for total solids emission the remaining 1.0 percent must therefore be tars and carbon.

As a check on this, the analyses of stack samples and chimney deposits from hand-fired installations show 75 to 84 percent of the solids (averages) are carbon and tars.[59, 67] Again using 1.2 percent of the fuel weight emitted as solids these analyses indicate 0.9 to 1.0 percent of the fuel fired will be emitted on the basis of ash balances.

The factors of estimation used for hand-fired furnaces were therefore:

Particulates (ash) = 0.002 lbs. per lb. coal fired (B-37)

Particulates (carbon and tars) = 0.010 lbs. per lb. coal fired (B-38)

Particulates (total) = 0.012 lbs. per lb. coal fired (B-39)

Stoker-fired furnaces. Stokers used in coal-fired home furnaces are either of the underfeed or overfeed types. Stack samples of solids emissions from the former type[68] indicate that approximately 0.6 percent of the fuel weight is emitted to the atmosphere. This is composed of about 70 percent carbon and tars and 30 percent ash. Ash balances on overfeed stokers[66] indicate that ash emission is about 0.1 percent of the fuel fired. Carbon and tars production from this type stoker is similar to that from underfeed stokers. Using the above data, estimating factors were determined for stoker-fired furnaces (average of underfeed and overfeed types):

Particulates (ash) = 0.0015 lbs. per lb. coal fired (B-40)
Particulates (carbon and tars) = 0.004 lbs. per lbs. coal fired (B-41)
Particulates (total) = 0.006 lbs. per lb. coal fired (B-42)

Coal-burning stoves. A considerable portion of the coal burned domestically is still burned in hand-fired or stoker-fired stoves (for space and water heating and for cooking). Particulates emission from the latter type is similar to that from stoker-fired furnaces. Particulates emission from hand-fired stoves, however, is considerably higher than from hand-fired furnaces. This is due to less efficient combustion and more frequent firing. No tests for the determination of particulates emission from this type of firing appear to have been made in this country. Combustion in hand-fired stoves may, however, be considered roughly comparable to the closeable-grate coal burning devices used in England. Many estimates have been made of particulates emissions from this combustion method. The latest estimates are 2.7 percent of fuel fired emitted as total particulates (0.3 and 2.4 percent of fuel fired as ash and carbon plus tars, respectively).

These figures were used directly for hand-fired coal stoves as follows:

Particulates (ash) = 0.003 lbs. per lb. coal fired (B-43)

Particulates (carbon and tars) = 0.024 lbs. per lb. coal fired (B-44)

Particulates (total) = 0.027 lbs. per lb. coal fired (B-45)

Particle size of solids emitted. No determinations of particle size of particulates emissions from domestic coal firing processes have been reported. It is possible to determine, very approximately, the most probable size characteristics of these particulates from measurements of suspended smoke. According to Meetham,[69] suspended smoke from coal burning has a median size (by count) of 0.075 μ with 0.02 percent by number greater than 1 μ and 0.001 percent by number greater than 2 μ. These data when plotted on log-probability paper and converted to a weight basis show a mass median diameter of 0.32 μ and standard geometric deviation of 2.0. Expressed another way, 95 percent of the weight of the suspended particles is due to sizes less than 1.0 μ. Meetham also shows that all combustibles (tars and carbon) emitted in coal burning operations, 63 percent remains suspended and can be considered "smoke." The remainder falls out of the atmosphere in a very short time. Using these data, 0.95 times 63 equals 60 percent (by weight) of the carbon and tars emitted are as particles less than 1 μ in diameter. If the size of ash particles emitted is considered greater than 1 μ then an approximate size analysis of particulate emissions from domestic coal firing, on the basis of 1 lb. of coal fired is as given in Table B-6.

Industrial Fuel Oil Combustion

Sulfur dioxide and sulfur trioxide. Comprehensive effluent sampling from fuel oil burning operations have been made.[70, 71] These tests indicate that all the sulfur in the fuel oil is burned to the oxides. Using the factors for the ratio of sulfur dioxide to sulfur trioxide in flue gases,[49] the estimating factors were calculated as follows:

SO_2 = 1.8 S lbs. per lb. fuel oil fired (B-46)

SO_3 = 0.2 S lbs. per lb. fuel oil fired (B-47)

Oxides of nitrogen and other gases. The same tests [70, 71] have established the following factors for non-sulfur gases:

Oxides of nitrogen (as NO_2) = 0.013 lbs. per lb. fuel oil fired (B-48)

Organic acids (as acetic) = 0.015 lbs. per lb. fuel oil fired (B-49)

Aldehydes (as CH_3CHO) = 0.0018 lbs. per lb. fuel oil fired (B-50)

Ammonia = 0.000006 lbs. per lb. fuel oil fired (B-51)

It is possible that other gases such as hydrocarbons, halides, HCN, H_2S, etc. may be emitted. Reliable sampling data are now, however, available upon which to base estimating factors.

Particulates. Testing in Los Angeles[70, 71] has established the following factor:

Solids (total) = 0.00025 lbs. per lb. fuel oil fired (B-52)

The analysis of these particulates is probably similar to that of the particulates emitted in refinery fuel oil firing, i.e., fine carbon, tars, metallic oxides. Particle size information is not available. On the basis of Meetham's data[69] and since no entrainment of fuel particles is likely as in the case of solid fuels, it is safe to assume that these solids are all less than 1 μ in diameter.

Domestic and Commercial Fuel Oil Combustion

The Los Angeles tests[70, 71] indicate that there is little difference between emissions from industrial and other fuel oil burning processes. The combustion of fuel oil is evidently similar. Some gaseous hydrocarbon emissions are likely from domestic and commercial units. The following was used:[70, 71]

Total hydrocarbons = 0.005 lbs. per lb. fuel oil fired (B-53)

Industrial Natural Gas Combustion

Sulfur dioxide and sulfur trioxide. Data from the Los Angeles tests[70, 71] indicate 0.000027 lbs. of sulfur oxides (as SO_2) emitted per lb. of fuel fired. Using the sulfur content of the fuel reported,[72] 0.4 grains per cu. ft., this shows 100 percent conversion of the sulfur in the fuel to sulfur oxides. As in the case of fuel oil burning, sulfur gas production, calculated on the basis of 100 percent conversion, yields the following:

SO_2 = 1.8 S lbs. per lb. gas fired (B-54)

SO_3 = 0.2 S lbs. per lb. gas fired (B-55)

Oxides of nitrogen. Estimates of nitrogen oxides production, based on effluent analyses, range from 0.007 lbs. (as NO_2) per lb. fuel fired[70, 71] to 0.0035 lbs. (as NO_2) per lbs. fuel fired.[72, 73] The average of the two value was used.

Oxides of nitrogen (as NO_2) = 0.005 lbs. per lb. gas fired (B-56)

Aldehydes. The estimate of 0.0015 lbs. (as CH_3CHO) per lb. gas fired from Los Angeles tests [70, 71] is much higher than two independent estimates of 0.00037 lbs. (as CH_3CHO) per lbs. gas fired.[72, 73] The latter value was used therefore:

Aldehydes = 0.0004 lbs. (as CH_3CHO) per lb. gas fired (B-57)

Other gases. The Los Angeles tests[70, 71] have established the following factors for other gaseous emissions from industrial natural gas firing:

Organic acids (as acetic) = 0.0012 lbs. per lb. gas fired (B-58)

Ammonia = 0.000006 lb. per lb. gas fired (B-59)

Again, other gaseous emissions are possible but reliable estimates are not made due to lack of information.

Particulates. It has been shown possible for particulates to be produced in natural gas combustion due to polymerization of gaseous combustion products at high temperature.[74] However, no measurements have been made of these emissions from typical gas burning processes.

Domestic and Commercial Natural Gas Combustion

Oxides of nitrogen. Nitrogen oxides production from domestic and commercial natural gas burning operations is, in general, less than from industrial natural gas burning operations. This is due to lower combustion temperatures. A recent estimate, based on effluent sampling,[75] indicates the following factor:

Oxides of nitrogen (as NO_2) = 0.004 lbs. per lb. gas fired (B-60)

Hydrocarbons. Los Angeles tests[70, 71] have established the following factor:

Total Hydrocarbons = 0.0015 lbs. per lb. gas fired (B-61)

Aldehydes. Aldehyde production is also significantly different in domestic and commercial gas burning processes. In this case aldehyde production is greater from domestic and commercial firing than from industrial firing. The explanation is that the lower combustion efficiency does not produce as complete a conversion of the aldehydes to CO_2 and water. Based on the data of Faith[72] and Hall[73] and average estimating factor for domestic natural gas burning is as follows:

Aldehydes (as CH_3CHO) = 0.0006 lbs. per lb. gas fired (B-62)

Other gases. The production of other pollutant gases is not significantly different than that from industrial firing.[70, 71] The estimating factors for industrial gas burning were used.

Particulates. See Industrial Natural Gas Burning above.

Waste Wood Burning

Sulfur oxides, nitrogen oxides, hydrocarbons, organic acids, aldehydes. These gases have been sampled in the effluent from wood waste burning in a silo-type incinerator.[70] Estimating factors as determined from these data are:

Sulfur oxides (as SO_2) = 0.00008 lbs. per lb. wood fired (B-63)

Oxides of nitrogen (as NO_2) = 0.0006 lbs. per lb. wood fired (B-64

Total hydrocarbons = 0.010 lbs. per lb. wood fired (B-65)

Organic acids (as acetic) = 0.0002 lbs. per lb. wood fired (B-66)

Aldehydes (as CH_3CHO) = 0.0009 lbs. per lb. wood fired (B-67)

Fluorides and other gases. Estimation of the emission of fluorides has been based on the fluoride content of the wood burned.[76] Using a fluorine content of 3 ppm (by weight)[77] the estimating factor for fluorides is:

Fluorides (as HF) = 0.000003 lbs. per lb. wood fired (B-68)

Other gases, such as SO_3, H_2S, HC1, NH_3, etc., may be emitted in wood waste burning. Effluent analyses upon which to base estimating factors for these gases are not available.

Particulates. In waste wood burning operations[70] particulate emission from silo-type incinerators average 2.6 lbs. per ton wood fired, or

Particulates = 0.0013 lbs. per lb. wood fired (B-69)

These particulates are composed of carbon, tars, and resinous fine particles with some coarse unburned fuel and inorganic ash particles.[70] Using data from the Los Angeles County Air Pollution Control District [78] a typical size frequency analysis shows a mass median diameter of 16 microns with a standard geometric deviation of 3.0. From these figures it can be shown that approximately 0.7 percent by weight of these particles are less than 1.0 μ in diameter.

Internal Combustion Engines (Gasoline)

Sulfur oxides. According to Magill et al.[79] a typical sulfur content of automotive gasoline is 0.25 percent by weight. On the basis of 100 percent conversion of this to sulfur oxides during combustion and an average gasoline density of 6.0 lbs. per gal. (RVP = 9.4 lbs.), total sulfur oxides production is as follows:

Oxides of sulfur (as SO_2) = 0.030 lbs. per gal. gasoline burned. (B-70)

Oxides of nitrogen. Nitrogen oxides production during gasoline combustion varies with the age of the automobile and the type of driving conditions. For 1950 and 1951 cars nitrogen oxides production (as NO) varies from nil during idling to 0.065 lbs. per gal. burned during steady driving.[79] To obtain an estimate for normal city driving patterns the data of Magill, Hutchinson, and Stormes[79] were used: acceleration, 23 percent of gasoline consumed; steady driving, 53 percent of gasoline consumed; deceleration, 18 percent of gasoline consumed; and idling, 4 percent of gasoline consumed. On this basis, a weighted average of nitrogen oxides production was determined as follows:

Oxides of nitrogen (as NO_2) = 0.056 lbs. per gal. gasoline burned (B-71)

It is possible that this estimate may be in error by ± 25 percent or so because of the newer models of automobiles now in use. However, at the time of these tests the cars tested were only one or two years old.

Aldehydes. Aldehyde production is also related to driving conditions. The data of the Los Angeles County Air Pollution Control District[16] when weighted according to city driving conditions (as above) yield:

Aldehydes (as CH_3CHO) = 0.0073 lbs. per gal. gasoline burned (B-72)

Organic acids. Similarly, the Los Angeles data[16] when weighted for city driving conditions yield:

Organic acids (as CH_3COOH) = 0.0040 lbs. per gal. gasoline burned (B-73)

Ammonia. Magill and Benoliel[71] suggest an average emission factor, for city driving, of 0.7 lbs. per ton of gasoline. This is equivalent to:

Ammonia = 0.0021 lbs. per gal. gasoline burned (B-74)

Hydrocarbons. Analyses of hydrocarbon constituents of automobile exhaust gases have been made.[79] According to these data, and based on a city driving pattern, the emission factors were calculated to be:

Methane = 0.050 lbs. per gal. gasoline burned (B-75)

Ethane = 0.099 lbs. per gal. gasoline burned (B-76)

C_3-C_5 Paraffins (MW = 58) = 0.104 lbs. per gal. gasoline burned (B-77)

C_6 + Paraffins (MW = 93) = 0.112 lbs. per gal. gasoline burned (B-78)

Ethene = 0.111 lbs. per gal. gasoline burned (B-79)

C_5 Olefins (MW = 70) = 0.076 lbs. per gal. gasoline burned (B-80)

C_6 Olefins (MW = 84) = 0.093 lbs. per gal. gasoline burned (B-81)

C_7 Olefins (MW = 100) = 0.100 lbs. per gal. gasoline burned (B-82)

Acetylene = 0.038 lbs. per gal. gasoline burned (B-83)

Benzene = 0.013 lbs. per gal. gasoline burned (B-84)

Other Aromatics (MW = 92) = 0.013 lbs. per gal. gasoline burned (B-85)

Particulates. Los Angeles data[16] when weighted to city driving patterns[79] yield the following factors for carbon and tars:

Ether soluble aerosols (Tars) = 0.0076 lbs. per gal. gasoline burned (B-86)

Non-Ether soluble aerosols (Carbon) = 0.0064 lbs. per gal. gasoline burned (B-87)

For oil mist, these same data[16] indicate the following:

Oil Mist (motor oil) = 0.012 lbs. per gal. gasoline burned (B-88)

For lead compounds, Hirschler et al.[80] indicate that about 40 percent of the lead in leaded gasolines is emitted as particulate matter in automotive exhaust gases during city driving. The remainder is deposited in the engine lubricating oil, and exhaust system. The most common composition of these particulates is as PbC1.Br, the halides being present in additives. Using an average value of 1.38 ml tetraethyl lead per gallon of gasoline[79] these data were calculated to be:

Lead compounds (as PbCl·Br) = 0.0020 lbs. per gal. gasoline burned (B-89)

The particulates emitted from automobile exhaust pipes (carbon, tars, lead compounds) have been studied[81] and the experimental data indicate that most aerosol particles are less than 1.0 μ in diameter. The mist emitted from engine blowby pipes may also be assumed to be less than 1.0 μ in diameter. It probably possesses size characteristics similar to the submicron sized oil smokes generated by the vaporization-condensation technique for experimental purposes.[82]

Internal Combustion Engines (Diesel)

Sulfur oxides. Typical average sulfur content of diesel fuels ranges from 0.11 percent (premium grade fuel) to 0.52 percent (regular grade fuel)[83]. On the basis of 100 percent conversion of the sulfur to the oxides during combustion and an average diesel fuel density of 6.8 lbs. per gal., total sulfur oxides production is as follows:

Regular fuel, oxides of sulfur (as SO_2) = 0.071 lbs. per gal. fuel burned (B-90)

Premium fuel, oxides of sulfur (as SO_2) = 0.015 lbs. per gal. fuel burned (B-91)

Oxides of nitrogen, aldehydes, organic acids. The production of these pollutant gases have been measured in the exhausts of cruising diesel buses.[16] In terms of pounds of pollutant per gallon of fuel burned,

Oxides of nitrogen (as NO_2) = 0.222 lbs. per gal. fuel burned (B-92)

Aldehydes (as CH_3CHO) = 0.016 lbs. per gal. fuel burned (B-93)

Organic acids (as CH_3COOH) = 0.031 lbs. per gal. fuel burned (B-94)

Hydrocarbons. Total hydrocarbons emission from diesel coaches has been measured as a function of driving conditions.[84] These data can be used to calculate average emission under city driving conditions using the data of Elliot.[85] The latter data show, for an average of experience in these cities the following: percentage of fuel consumed in idling, 30 percent; in acceleration, 17 percent; in crusing, 33 percent; and in deceleration, 20 percent. A weighted average emission rate for city driving is:

Total hydrocarbons = 0.715 lbs. per gal. fuel burned (B-95)

Particulates. Particulate emission has been measured only in terms of the non-ether soluble component (carbon).[16] These data indicate the following emission factor:

Non-ether soluble aerosols (carbon) = 0.086 lbs. per gal. fuel burned (B-96)

The particle size characteristics of these particulates may be assumed similar to those of aerosols found in gasoline engine exhausts,[81] i.e., all particles are less than 1.0 μ in diameter.

APPENDIX C

DETAILS OF METEOROLOGICAL STUDY METHODS, EQUIPMENT, AND INSTRUMENT LOCATIONS

INSTRUMENT LOCATIONS

Station 1 was located in the southeast quadrant of E. Leland Taylor Park, a small municipal park in a generally residential neighborhood. The ground elevation was 450 feet MSL. A bathhouse about 12 feet high was 160 feet east-northeast of the site, and scattered trees 180 feet north. Short grass surrounded the site.

Station 3 was in the southwest corner of a field, with corn, in season, growing within 10-15 feet of the fence surrounding the site. On the other side of a dirt road about 30 feet west of the site was a field in which produce was grown. A cornfield also lay to the southeast. A farm house 18 feet high was 250 feet southwest of the site. The station was at a ground elevation of 450 MSL.

Station 7 consisted of two sites within the Rubbertown industrial complex. The du Pont site was a pre-existing installation of the E. I. du Pont de Nemours Company, which was designated as station 7 in this study. The wind equipment was located on a 20 foot open frame tower on a building roof, with the wind transmitters 96 feet above ground. Ground elevations was 450 feet MSL. Buildings averaging 40 feet in height surrounded the site. The Goodrich site was also at a ground elevation of 450 feet MSL. Wind sensing elements were mounted on a 55 foot tower. The closest building, about 20 feet high, was 200 feet to the west-southwest. There were other buildings averaging 35 feet in height throughout the southern semi-circle at distances of 400 to 500 feet. Short grass surrounded the site.

Station 8 was located in a tract of unimproved land, formerly used as a gravel pit, in a mixed residential and industrial neighborhood, at a ground elevation of 460 feet MSL. A gravel chute 25 feet high was 40 feet to the east-southeast of the site, and residences 15 to 20 feet in height were 200 feet to the west-southwest. Weeds surrounding the site grew to a height of three feet in season.

Station 9 was on the bank of the Ohio River, about 300 feet north of a levee and 600 feet south of the river, at a ground elevation of 430 feet MSL. The top of the levee was 30 feet higher than the site, and the river at normal pool elevation 50 feet lower. The station was located midway between two pump houses 12 feet square and 22 feet high 30 feet to the north and south. The area between the pump houses was enclosed by a fence. There were 20-foot trees 35 feet to the west. Weeds outside the fenced area grew to a height of three feet in season.

Station 10 was located atop a knoll at a ground elevation of 760 feet MSL. A fringe of bushes and trees, mostly deciduous, surrounded the crest of the knoll, forming a clearing one-half to three-fourths mile in diameter within which the installation was made. A clump of trees 25 feet high was about 20 feet south of location, and another clump 30 feet high about 100 feet north. Short grass surrounded the site. The nearest part of the fringe surrounding the knoll was about 150 yards to the north.

Station 11 was located in the downtown section of the city. The installation was on the WHAS TV tower, which had a base elevation of 455 feet MSL, and was located in the southeast corner of a parking area 300 feet square. Buildings averaging 40 feet high were

300 feet to the north and west, and buildings 75 feet high were in the southeast quadrant at an average distance of 125 feet.

The Weather Bureau Airport Station at Standiford Field was designated as station 12 for this study. The ground elevation there is 474 feet MSL. There were no obstacles in the immediate vicinity of the location.

Station 13 was located on a ridge of high ground extending south-eastward from the line of hills paralleling the Ohio River on the Indiana side. The land dropped off abruptly to the south and east to the level of the flood plain of the river. The ground elevation at the site was 635 feet MSL. There were 30-foot buildings 60 feet to the east and west, and a 55-foot tree 25 feet to the northwest. Short grass surrounded the site.

WIND MEASURING SYSTEMS

Beckman and Whitley Model K100A Wind Speed and Wind Direction Recording Systems were installed at stations 1, 3, and 8, and at the Goodrich site, station 7, to measure surface airflow. The system consisted of four main units as follows:

1. A wind speed transmitter assembly and a three cup anemometer. The assembly consisted of a light source and photocell which emitted photo-electric pulses at a rate proportional to the rate of revolution of the cups (two impulses per cup revolution).

2. A wind direction transmitter assembly and vane, which transmitted a direct current proportional to the angular displacement of the wind vane from a fixed azimuth bearing by means of a micro-torque potentiometer. The potentiometer had a six degree gap, so that the output from the assembly varied from full scale to zero (or vice versa) as the vane rotated through the gap.

3. A translator which produced direct current analogues proportional to the rate of rotation of the cup assembly and the angular displacement of the wind vane.

4. Wind speed and direction recorders, which were 1400 ohm Esterline-Angus recording milliameters measuring the direct current analogues from the translator unit.

A 0 to 30 mph range was selected to record the wind speed. Wind direction was recorded on a 360-degree range. The selected chart drive rate of three inches per hour provided 15 2/3 days of record per chart roll.

Each 55 foot instrument tower was located at the center of a triangular fenced enclosure, measuring 60 feet on each side. To facilitate erection of the tower and orientation of the wind vane, it was advantageous to orient one side of the fence to a true east-west line and install the gate to the enclosure in the center of that side of the fence. Each wind vane was oriented so that the center line of the recorder corresponded to the vane pointing west. With this orientation, the six degree gap in the potentiometer corresponded to a position of the vane between 84 and 90 degrees from north, i. e. the vane pointing east. The gap in the potentiometer was located this way to provide as much information as possible on winds from Rubbertown to the West End area, while minimizing loss of information on winds from the opposite sector.

Routine maintenance and servicing of this equipment was performed during visits to each installation on Mondays, Wednesdays, and Fridays. An occasional difficulty was encountered with the regulator power supply in using the system on 115 volt AC power. The power unit uses a 6AS7 electron tube as a DC voltage regulator to the translator unit and, with continuous usage, the output voltages would decrease until they were too low to operate the translator properly. The operating life of these electron tubes was about six months.

Difficulty with the bearings in both the wind direction and wind speed transmitters was encountered after approximately ten months of continuous service. Due to the construction of these transmitters, it was necessary to return them to the manufacturer for repair. The transmitters were very sensitive to dirt and dust, requiring frequent cleaning with water.

The wind vane was attached to the transmitter shaft by means of a small spring type holding device which weakened after a few months use, allowing the vane to rotate five to ten degrees without moving the potentiometer contact. This difficulty could be temporarily remedied by carefully bending the spring, in case no replacement parts were available. A later modification of the equipment by the manufacturer eliminated this defect.

Verticality of the towers was checked at approximately bi-monthly intervals. If adjustments were necessary, the orientation of the wind vane was also checked. The vane orientation was also checked approximately every six months whether or not any adjustments for verticality had been made.

Recorder charts were rewound, dated, stamped, and examined for necessary time adjustments and periods of bad record, in preparation for data reduction. The following are the entries made and the reduction techniques employed:

Wind Speed

1. Hourly average wind speed was determined to the nearest mile per hour by the "equal area" method, an inspective technique in which the hour's trace is divided into equal areas by the hourly average speed.

2. Hourly maximum wind speed was read to the nearest mile per hour.

3. Hourly minimum wind speed was read to the nearest mile per hour.

4. Hourly wind speed range was calculated by subtracting the minimum hourly wind speed from the maximum hourly wind speed.

Wind Direction

1. Hourly average wind direction was determined by the "equal area" method and was expressed as one of the 16 compass points, i. e., N = 348 3/4 to 011 1/4 degrees, etc., calm, or missing. When the average wind direction was at or near the position corresponding to the gap in the potentiometer, recording at the edges of the chart, a "painting" effect occurred as the pen alternated between zero and full scale deflection. If this "painting" was equally distributed over the full chart scale, the direction assigned to the edge of the chart (east) was the average direction. If the wind direction could not be determined, an "x" was recorded. If the average wind direction was doubtful or estimated, the direction was recorded in parentheses. If a single wind direction could not be assigned to at least a twenty minute segment of the trace because of the variation of direction within the hour, "calm" was recorded. The "calm" classification was used only when the air showed no consistent direction of motion. This classification was not necessarily related to wind speed.

2. Persistence of the average wind direction from hour to hour was recognized by three conditions: a. When the direction during the previous hour differed by two or more compass points from the current hour, recorded as "0". b. When the direction during the previous hour differed by one compass point from the current hour, recorded as "1". c. When the direction during the previous hour was the same as the current hour, recorded as "2".

3. Fifth highest veering direction in the hour was read to the nearest multiple of five degrees.

4. Fifth highest backing direction in the hour was read to the nearest multiple of five degrees.

5. Hourly wind direction range was computed as the angle, in degrees, from the fifth highest veering value to the fifth highest backing value through the average wind direction.

6. Hourly damping of the wind direction trace was recognized by three conditions: a. No damping - continuous short term fluctuations, recorded as "0". b. Partially damped - short term fluctuations which exceed one half hour and may or may not be continuous, recorded as "1". c. Partially or completely damped - short term fluctuations which do not exceed one half hour and may not be continuous, recorded as "2".

The Beckman and Whitley Wind System, although not designed for continuous long-period operation, performed quite well when the necessary preventive maintenance program was used. This maintenance was time-consuming, and required the services of experienced personnel. The chart records were satisfactory, except for two problems: the "painting" effect when the wind direction was recorded near the edges of the chart; and the formation of a band with a width corresponding to several mph on the wind speed record with very light winds (less than about two mph), because of the low rate at which the wind speed transmitter generated impulses at these low speeds.

A Bendix-Friez Aerovane Wind Speed and Wind Direction Recording System was installed at the 524 foot level on the WHAS TV tower station 11). It was selected because it was a sturdy and reasonably accurate continuous recording instrument for measuring wide ranges of wind speed. The wind direction transmitter employed a synchro system which electrically transmitted the position of the vane to a similar synchro in the recorder. A continuous contact was maintained for any degree of rotation. The wind speed transmitter, driven by a three-bladed impeller, utilized a tachometer magneto-voltmeter system which electrically transmitted a voltage proportional to the wind speed to the recorder. The wind direction and speed transmitters were contained in one unit. Inked traces of wind speed and wind direction were simultaneously produced on a continuous paper chart by the two-channel recorder. The recorder had a wind speed range of 0 to 120 knots and a wind direction range of 540 degrees of azimuth. A chart drive rate of three inches per hour was selected.

Processing of the chart rolls preparatory to data reduction was similar to that for the charts from the Beckman and Whitley System. Hourly average wind speed and hourly average wind direction were determined by methods similar to those used for the Beckman and Whitley records. The range of the recorder chart, 540 degrees, provided a 180-degree overlap, so that there was no problem of "painting" at the edges of the chart roll. This wind system, except for two mechanical defects corrected by the manufacturer, required very little attention for maintenance and servicing. Its performance was completely satisfactory.

An Instruments Corporation Anemograph Model R-339 Wind Speed and Wind Direction Recording System, a pre-existing installation of the E. I. du Pont de Nemours Company, was in continuous operation through the period of the study. This system had operating characteristics similar to the Bendix-Friez Aerovane System. The wind speed sensing element, a three-cup anemometer, and the direction sensing element, a split-tail vane, were separately mounted on a cross arm. The recorder produced continuous simultaneous inked traces, in separate channels, of wind direction and speed. The recorder range was 360 degrees for wind direction, and 0 to 75 mph for wind speed.

Half-hourly values of average wind speed and direction, and the speed and direction ranges, were determined from the chart records, and furnished to the study through the courtesy of the du Pont Company. These values were obtained by du Pont personnel by reduction methods similar to those described for the Beckman and Whitley System records; average wind speed was recorded to the nearest one-half mph, and average direction to the nearest five degrees. These entries were further reduced so that they would be comparable to the hourly values computed from the Beckman and Whitley System records. Because the original chart rolls were not available and the data received were reduced on a half-hourly time interval basis, the fifth highest veering and backing directions could not be determined directly. Otherwise, the recorded data are, ignoring differences due to instrument characteristics, similar to the data from stations 1, 3, and 8.

HYGROTHERMOGRAPH OPERATIONS

In preparation for data reduction, hygrothermograph charts were dated, stamped, and examined for periods of bad record. Necessary adjustments for intervals of missing record due to faulty operation were made and corrections indicated by the thermometer readings were entered on the charts. The following entries were made on data sheets:

Temperature

1. Hourly average temperature to the nearest half degree F. determined by the "equal area" method.

2. Daily maximum temperature to the nearest half degree F.

3. Daily minimum temperature to the nearest half degree F.

Relative Humidity

1. Hourly average relative humidity to the nearest whole percent, determined by the "equal area" method.

2. Daily maximum relative humidity to the nearest whole percent.

3. Daily minimum relative humidity to the nearest whole percent.

The hygrothermograph proved to be a dependable instrument. The regular servicing during the study kept the accuracy of this instrument at an optimum level.

PRECIPITATION MEASUREMENTS

The Instruments Corporation Universal Recording Raingage was selected for use in the study because it was a readily obtainable, continuous recording raingage. The record was obtained through a weighing system matched to the receiver so that the trace produced on the chart was a direct representation, in inches, of the accumulated rainfall. The chart was on a spring-driven revolving drum, with a rotation speed of one revolution per 24 hours. The chart range was from 0 to 6 inches. The charts were allowed to make two revolutions between chart changes because of the existing three day-a-week servicing schedule, with three revolutions for the Friday-Monday chart.

In preparation for data reduction, the charts were dated, stamped, and examined for periods of bad record.

Hourly rainfall amount to the nearest one hundredth of an inch was determined by subtracting the amount of rainfall recorded at the beginning of each hour from the amount of rainfall recorded at the end of the hour.

This instrument performed satisfactorily. Standard Weather Bureau data reduction procedures were used.

SOLAR RADIATION MEASUREMENTS

An Instruments Corporation pyrheliograph was operated to obtain a record of total (direct plus diffuse) radiation received on a horizontal surface. The instrument operates on a differential thermometer principle. The instrument had two bimetalic strips which bent according to their temperature. A blackened strip absorbed radiation, while the other reflected radiation from a polished surface. These strips were linked together in such a way that when the ambient temperature changed, the amount of bending of these strips was the same, with one compensating for the other. However, radiant energy caused the blackened strip to be heated more than the reflecting strip, and this differential was measured through a linkage system to a pen which recorded the deflection on a spring-driven revolving drum. The recorder chart range was zero to three gram calories per square centimeter per minute. The drum speed was one revolution per 24 hours. The charts were checked, dated, and stamped in preparation for data reduction. Hourly average incoming solar radiation was determined to the nearest one tenth of a langley (gram-calorie per square centimeter per minute) by the "equal area" method.

The accuracy of this instrument was affected by cleanliness, especially of the glass dome and of the reflecting plate. It was noted that the lower surface of the glass dome would sometimes accumulate condensation. The effect of this condensation on the accuracy of the instrument is not known, but it is assumed to introduce an error. It is recommended that this instrument contain some type of a drying agent to eliminate condensation. Daily servicing trips required to change the recorder chart were inconvenient. A two or four-day chart and drum mechanism would have provided sufficient detail for the purpose of the study.

VERTICAL TEMPERATURE GRADIENT MEASUREMENTS

A Beckman and Whitley Model 233-1 Temperature Gradient Control Unit was installed on the 55 foot tower at station 1, with temperature sensing elements mounted at six feet and 55 feet above ground on supporting brackets extending two feet from the tower.

Two aspirated thermistor compensated thermocouples contained in radiation shields were used for temperature sensing elements. The output of the thermocouples was detected and amplified by a Leeds and Northrup photo cell galvanometer. An Esterline-Angus 1400 ohm recorder was used for continuous recording of temperature difference between the two elements. The recorder range was 15 degrees C. and the zero temperature difference line was set so that temperature differences between the upper and lower sensing elements from minus five to plus ten degrees C. were recorded. The chart speed selected was six inches per hour.

The factory calibration was considered sufficient. However, the instrument manufacturer, upon request, sent a calibrated input testing device to check the installation. This testing device supplied a known voltage to the input, and the recorder results could be checked for several conditions of simulated temperature difference,and for any simulated ambient air temperature.

The system as originally received was not capable of providing a continuous record. After changing from DC to AC power, and changing aspirator motors, the system performed satisfactorily. Some interference from 115 volt AC power lines adjacent to the thermocouple leads was detected, but was overcome by running the leads through shielded conduits. The sensitivity of the galvanometer required extra precautions to insure that no motion from vibration or other causes would create spurious motions of the galvanometer mirror.

A Leeds and Northrup Temperature Difference Measuring System was installed on the WHAS TV tower, by a local electrical contracting company. This system consisted of three shielded, aspirated thermohm sensing units and a Speedomax recorder. The thermohm units were installed at 60 feet, 170 feet, and 524 feet above the ground on five foot steel beams hinged to the tower. The units could be swung toward the tower horizontally for servicing and maintenance. The Speedomax recorder was basically a resistance measuring and recording meter, printing instantaneous values of reference temperature from the lowest thermohm unit, temperature difference between the lowest level and the middle level, and temperature difference between the lowest and the highest level, in rotation. The time interval between each print was 1 minute and 55 seconds, or roughly six minutes between successive printings of the same element.

The system was calibrated at the factory. However, due to a defect in the pig-tail leads at the recorder end of the cable, it was necessary to replace these leads and reset the system after installation.

The system was installed on June 7, 1957, but, because of the above difficulties and a power outage, reliable records were obtained beginning with July 30, 1957.

This system, as modified in the field, has given satisfactory performance. An outstanding feature is the little maintenance required to maintain satisfactory performance

The AN/UMQ-4 wiresonde system provided a measure of temperature from the surface to a maximum altitude of about 1000 feet. It was completely battery operated. The four main units of the system used were:

1. The "Kytoon", an air foiled balloon flying partly on the principle of a balloon and partly on the principle of a kite.

2. The wiresonde unit, consisting of a housing for a battery operated blower, mounting facilities for the thermistor and humidity elements, and a removable radiation shield. The thermistor could be used for dry or wet bulb readings and was a resistance-head type.

3. The cable reel, a manually operated drum equipped with 2000 feet of transmission-mooring cable. The reel was equipped with a counter for indicating the number of feet of cable out. A clinometer was used to measure the elevation angle of the Kytoon.

4. The summation bridge unit, consisting of four Wheatstone Bridge circuits and associated controls. Two bridge circuits were used for temperature measurements and two more were available for humidity measurements.

The system was mounted on a specially built two wheel trailer. The bridge and reel units were mounted on collapsible stands in the trailer and accessory compartments were built around one end of the trailer. Wiring connections were provided for attachment to the towing vehicle battery for night time operations. A rack to hold a tank of helium was welded to the trailer. A folding canvas top was designed to protect the instruments when not in use and to serve as a canopy for the bridge operator when the system was in use. Scissor type jacks were attached to each of the four corners of the trailer as stabilizers when the wiresonde system was in use.

To conduct wiresonde operations, a Certificate of Waiver from the Civil Aeronautics Administration was required. This Certificate of Waiver contained special conditions and limitations which had to be adhered to regarding time of operation, ceiling, visibility, and illumination of the balloon for nighttime operations.

Maintenance of the wiresonde equipment consisted of keeping the equipment clean, checking for loose connections, replacing batteries in the bridge, and lubricating the cable reeling machine. Occasionally it was necessary to replace the bladder in the Kytoon. This equipment was checked on a daily basis when in operation.

Measurements of temperature were made at pre-determined intervals of cable out. Temperature, length of cable out, and angle of elevation were recorded manually for each measurement. Humidity was not measured. The elevation of the Kytoon was then computed from the length of cable out and the elevation angle, according to the instruction book. The reduced data for each run were elevation above ground and temperature in degrees centigrade.

Considerable difficulty was encountered in humid weather with light winds because dew adhered to the Kytoon, destroying the lifting power, sometimes to such an extent that the ascent would have to be discontinued. This could be overcome by attaching another Kytoon to the cable to double the lift.

DATA REDUCTION

During the course of the study, over 400,000 items were recorded as reduced meteorological data. Data entered on the ledger sheets were transferred to punch cards. For each hour's data, one card was punched for each of the network's surface wind stations (1, 3, 7, and 8), and the data from the remaining sites were entered on a fifth card, resulting in 120 cards per day of full operation.

APPENDIX D

DETAILS OF SOME ANALYTICAL PROCEDURES USED IN AIR POLLUTANT ANALYSES

EXTRACTION OF BENZENE SOLUBLE MATTER FROM HIGH VOLUME PARTICULATE SAMPLES

1. Fold one half of the eight by ten inch filter into a small bundle so that all edges are covered, tie with a piece of copper wire, and place in a Soxhlet extractor.

2. Connect the extractor to a 125 ml. flat bottom boiling flask containing 75 ml. of benzene and two or three boiling chips.

3. Place the assembled apparatus (flask, extractor, and condenser) on a hot plate and extract the sample for eight hours.

4. Disconnect the flask, place on a hot plate under a hood, and evaporate to a volume of five to ten ml.

5. Filter the extract through a medium porosity fritted glass funnel into a weighed test tube.

6. Wash the flask with two to three ml. of acetone until no more color is removed.

7. Place the test tube in a 60 degrees C drying oven or water bath and evaporate the excess benzene and acetone. If a water bath is used, the test tube should be placed in a 60 degrees C oven for a few minutes before final weighing.

8. Cool the test tube and weigh.

A blank value of the benzene extractibles in the filter paper was determined. This blank, plus the residue from evaporating 75 ml. of benzene, was subtracted from all samples. The blank value was very low, in most cases being only one or two mg. The adjusted sample weight was then divided by the air volume sampled to give $\mu g/m^3$ of benzene solubles in the air sampled. Benzene soluble material in each sample was held for possible further analysis.

EXTRACTION OF WATER SOLUBLE CHLORIDES, SULFATES, AND NITRATES FROM HIGH VOLUME PARTICULATE MATTER SAMPLES

Water soluble chlorides, sulfates, and nitrates were extracted from half of the eight by ten inch high volume filter after benzene soluble material had been extracted. The procedure was as follows:

1. Place filter in a 250 ml. Erlenmeyer flask, add 50 ml. of distilled water, and bring to a gentle boil, swirling occasionally.

2. Simmer for about five minutes and filter through a dense paper such as Whatman No. 42. Thin paper does not give sufficient filtrate clarification and yields too high values in subsequent colorimetric and turbidimetric determinations.

3. Add 50 ml. of water to material retained on the filter and repeat procedure. Add water until filtrate volume is 100 ml. (All water used for reagent preparations and extractions was distilled and passed through a mixed resin bed of Rohm and Haas Amberlite MB-1 to remove trace impurities.)

4. Add one gram of Rohm and Haas Amberlite IR-120 (H) resin to the water extract. Shake sample and allow to stand overnight in order that the resin will reach equilibrium with the dissolved cations. This treatment removes iron and other metals which would interfere with the nitrate determination.

DETERMINATION OF CALCIUM IN HIGH VOLUME PARTICULATE SAMPLES

The calcium concentration in high volume filter paper samples (Whatman 41-H) was determined by taking a portion of the particulate sample, extracting it in 10 percent nitric acid, adjusting the acid concentration to the two percent with distilled water, filtering through Whatman 41-H filter paper, and burning the resultant filtrate in an oxyacetylene flame while scanning the emission spectrum through the two calcium wave lengths (422 and 554 mμ). Calcium concentrations were determined with a Beckman Model DU Spectrophotometer (Figure 2-5) with flame and photo multiplier attachments, a photo multiplier tube coupled to a Beckman Spectral energy recording adapter, and a Bristol strip chart recorder. The chart recorder eliminated tedious manual setting and reading that would have otherwise been required.

The calcium calibration curve was obtained by dissolving known amounts of reagent grade calcium carbonate in dilute hydrochloric acid, diluting the stock solution in two percent nitric acid, burning in an oxyacetylene flame, and determining the emission level on the spectrophotometer. Solutions containing 0; 500; 1000; 2000; 5000; 10, 000; and 20, 000 μg of calcium per liter were aspirated into the flame, using a slit width of 0. 025 mm., an oxygen pressure of ten psi, and an acetylene pressure of four psi. Emission intensity was measured at 422 and 554 m μ wave lengths with the photomultiplier tube operating at near maximum sensitivity. The spectrum was scanned through the two wave lengths as standard solutions were burned. A calibration curve of calcium concentration versus emission intensity was prepared from the results.

In order to maintain constant sensitivity, 5 mg. per liter of strontium solution was burned several times each day, and the 100 percent adjustment control on the spectral energy recording adapter was adjusted to a constant level. Strontium was used because of its sharp emission line at 460. 7 mμ wave length.

Time did not allow investigating all possible interferences of the calcium determination but some of the more important ones were checked. Sodium interference at the calcium wave lengths gave a plus 5 to 10 percent error when the sodium content was twice the calcium content, but such high sodium content was not expected in Louisville. Heavy metals, such as iron and manganese, gave a negative interference when present at 5 to 10 times the calcium level, but again, high concentrations of these metals were not expected.

Nitric acid was the solvent used for calcium analysis throughout the study. The literature indicates that hydrochloric acid is a better solvent for flame spectrographic work since there is some emission suppression with nitric acid. Comparative runs, using the two acids, indicated there was no significant difference for the levels of calcium encountered in Louisville.

APPENDIX E

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Table 2-1. FACTORS FOR ESTIMATION OF PROCESS LOSSES TO ATMOSPHERE IN PETROLEUM REFINING OPERATIONS[9]

Source	Pollutant	Estimating Factor	
1. Equipment leakage (valves, pumps, compressors)	Hydrocarbons	28 lbs. per 1000 bbl. crude throughput	
2. Equipment maintenance (blind changing, turnarounds, blowdowns)	Hydrocarbons	7 lbs. per 1000 bbl. crude througput	
3. Air blowing operations	Hydrocarbons	37 lbs. per 1000 bbl. fresh feed	
4. Vacuum jets	Hydrocarbons	54 lbs. per 1000 bbl. crude throughput	
5. Cooling towers	Hydrocarbons	10 lbs. per day per 1000 gpm cooling water	
6. Waste water separators	Hydrocarbons	218 lbs. per 1000 bbl. crude throughput	
7. Compressor engines	Hydrocarbons	18 lbs. per 1000 bbl. crude throughput	
	Oxides of nitrogen (as NO_2)	12 lbs. per 1000 bbl. crude throughput	
	Ammonia	2.9 lbs. per 1000 bbl. crude throughput	
	Aldehydes as CH_3CHO)	2.3 lbs. per 1000 bbl. crude throughput	
		Refinery fuel gas	Fuel Oil
8. Boilers and process heaters	Sulfur dioxide	1.95 lbs. per lb. sulfur in gas	0.95 lbs. per lb. sulfur in oil
	Sulfur trioxide	0.058 lbs. per lb. sulfur in gas	0.058 lbs. per lb. sulfur in oil
	Oxides of nitrogen (as NO_2)	0.23 lbs. per MCF gas burned	0.068 lbs. per gal. oil burned
	Aldehydes (as CH_3CHO)	0.045 lbs. per MCF gas burned	0.0009 lbs. per gal. oil burned
	Hydrocarbons (as hexane)	0.026 lbs. per MCF gas burned	0.0034 lbs. per gal. oil burned
	Org. acids (as acetic)	0.018 lbs. per MCF gas burned	0.014 lbs. per gal. oil burned
	Ammonia	0.0004 lbs. per MCF gas burned	0.0001 lbs. per gal. oil burned
	Particulates	0.021 lbs. per MCF gas burned	0.020 lbs. per gal. oil burned
9. Catalytic cracking regenerator stacks (fluidized bed type)	Sulfur dioxide and trioxide	Computed in with boiler and process heater losses	
	Hydrocarbons	220 lbs. per 1000 bbl. fresh feed	
	Oxides of nitrogen (as NO_2)	63 lbs. per 1000 bbl. fresh feed	
	Ammonia	54 lbs. per 1000 bbl. fresh feed	
	Aldehydes (as CH CHO)	28 lbs. per 1000 bbl. fresh feed	
	Hydrogen cyanide	0.1 lb. per 1000 bbl. fresh feed	
	Particulates	62 lbs. per 1000 bbl. fresh feed (without collector) (Solids from cyclone collector are 99.97% by weight 1 u)	
10. Filling losses from loading facilities (trucks, barges, tank cars)	Hydrocarbons	Use modified API* formulas**	
11. Storage tank losses (breathing, filling)	Hydrocarbons	Use modified API* formulas**	

*API - American Petroleum Institute

**See Appendix B

Table 2-2. FACTORS FOR ESTIMATING EMISSIONS OF PRODUCTS OF COMBUSTION FROM INDUSTRIAL FUEL BURNING (EMISSIONS IN LBS. PER LB. OF FUEL FIRED)

	Fuel			
	Coal	Fuel oil	Natural gas	Waste wood
Sulfur dioxide	1.75*	1.8S	1.8S	0.00008
Sulfur trioxide	0.2S	0.2S	0.2S	n.a.
Oxides of nitrogen (as NO_2)	0.010	0.013	0.005	0.0006
Total hydrocarbons	n.a.	b.m.d.	b.m.d.	0.010
Inorganic chlorides (as HC1)	0.002	n.a.	n.a.	n.a.
Fluorides (as HF)	0.0002	n.a.	n.a.	0.000003
Organic acids (as acetic)	n.a.**	0.015	0.0012	0.0002
Aldehydes (as CH_3CHO)	n.a.	0.0018	0.0004	0.0009
Ammonia (NH_3)	n.a.	0.000006	0.000006	n.a.
Particulates	see tables 2-3 and 2-4	0.00025	n.a.	0.0013

*S = lbs. sulfur per lb. of fuel.
** "n.a." indicates not available.
b.m.d. = below minimum detectable
Source: see Appendix B herein.

Table 2-3. PARTICLE SIZE CHARACTERISTICS OF PARTICULATES PRODUCED IN FUEL COMBUSTION

Fuel	Firing method	Mass median diameter; geometric mean(μ)	Standard geometric deviation	Percent by weight less than 1 μ
Coal, industrial	Underfeed stoker	20	3.9	3.0
	Travelling grate	75	2.0	<0.01
	Cyclone furnace	5	3.7	12.0
	Spreader stoker	57	4.1	0.2
	Pulverized coal	20	2.5	0.1
Coal, domestic and commercial	All methods: suspended carbon and tars	0.32	2.0	95
	all carbon and tars	-	-	60
	all ash	>1.0 μ	-	0.0
Fuel oil	Industrial and other burners	<1.0 μ	-	~100
Waste wood	Silo incinerators	16	3.0	0.7

Source: see Appendix B herein

Table 2-4. FACTORS FOR ESTIMATING EMISSION OF PARTICULATES FROM INDUSTRIAL COAL BURNING; ACCORDING TO FIRING METHOD (EMISSIONS IN LBS. PER LB. OF FUEL FIRED)

Firing method	Solids*
Underfeed stoker	0.15A**
Travelling grate	0.15A
Cyclone furnace	0.15A
Spreader stoker - dust reinjection	1.00A
Spreader stoker - no dust reinjection	0.60A
Pulverized coal	0.75A

* Ash and unburned fuel
** A = lbs. ash per lb. of fuel
Source: see Appendix B herein

Table 2-5. FACTORS FOR ESTIMATING EMISSIONS OF PRODUCTS OF COMBUSTION FROM DOMESTIC AND COMMERCIAL FUEL BURNING OPERATIONS (EMISSIONS IN LBS. PER LB. OF FUEL FIRED)

Pollutant	Fuel		
	Coal	Natural gas	Fuel oil
Sulfur dioxide	1.8S*	1.8S	1.8S
Sulfur trioxide	0.04S	0.2S	0.2S
Hydrogen sulfide	0.004S	n.a.	n.a.
Oxides of nitrogen (as NO_2)	0.0002	0.004	0.013
Total hydrocarbons	0.010	0.0015	0.005
Inorganic chlorides (as HCl)	0.002	n.a.	n.a.
Fluorides (as HF)	0.0002	n.a.	n.a.
Organic acids (as acetic)	n.a.**	0.0012	0.015
Aldehydes (as CH_3CHO)	n.a.	0.0006	0.0018
Ammonia	n.a.	0.000006	0.000006
Particulates	see table 2-6	n.a.	0.00025

Note: See table 2-2 for wood combustion.
*S = lbs. sulfur per lb. of fuel
**n.a. = not available
Source: see Appendix B herein

Table 2-6. FACTORS FOR ESTIMATING EMISSIONS OF PARTICULATES FROM DOMESTIC AND COMMERCIAL COAL BURNING ACCORDING TO FIRING METHOD (EMISSIONS IN LBS. PER LB. OF FUEL FIRED)

Firing method	Carbon and tars		Ash
	<1 μ	>1 μ	(>1 μ)
Hand-fired furnaces	0.006	0.004	0.002
Stoker fired furnaces and stoves	0.0025	0.0015	0.0015
Hand-fired stoves	0.014	0.010	0.003

Source: see Appendix B herein.

Table 2-7. FUEL CONSUMED IN DOMESTIC AND COMMERCIAL ESTABLISHMENTS IN WESTERN LOUISVILLE - 1956

Fuel	Firing Method	Quantity
Western Kentucky coal (a)	15% in hand-fired stoves 45% in hand-fired furnaces 40% in stoker-fired furnaces	138,000 tons
Eastern Kentucky coal (b)	15% in hand-fired stoves 45% in hand-fired furnaces 40% in stoker-fired furnaces	31,900 tons
Fuel oil (c) (Nos. 2 & 4)	All Methods	2,270,000 gals. (7.1 lbs./gal.)
Natural gas (d)	All methods	3.42 x 109 cu.ft. (0.045 lbs./cu.ft.)

(a) Sulfur content = 3.0% (by wt.) 86/

(b) Sulfur content = 0.7% (by wt.) 86/

(c) Sulfur content = 0.3% (by wt.) 13/

(d) Sulfur content = 0.00098% (by wt.) 87/

Table 2-8. FACTORS FOR ESTIMATING EMISSIONS FROM INTERNAL COMBUSTION ENGINES (EMISSIONS IN LBS./GAL. FUEL BURNED)

Pollutant	Fuel			
	Gasoline (automobiles, city driving)			Diesel fuel (buses-city driving; R. R. locomotives)
Gases				
Oxides of sulfur (as SO_2)	0.030			0.015 (a) 0.071 (b)
Oxides of nitrogen (as NO_2)	0.056			0.222
Aldehydes (as CH_3CHO)	0.007			0.016
Organic acids (as CH_3COOH)	0.004			0.031
Ammonia	0.002			n.a.
Hydrocarbons; total	0.815			0.715
Paraffins, total		0.365		
Methane			0.050	
Ethane			0.099	
C_3-C_5 (MW = 58)			0.104	
C_6 + (MW = 93)			0.112	
Olefins, total		0.380		
Ethene			0.111	
C_5 (MW = 70)			0.076	
C_6 (MW = 84)			0.093	
C_7 (MW = 100)			0.100	
Acetylene		0.038		
Aromatics, total		0.032		
Benzene			0.013	
Other (MW = 92)			0.019	
Particulates (all $<1\ \mu$)				
Carbon (non-ether sol.)	0.006			0.086
Tars (ether sol.)	0.008			n.a.
Oils (motor oil mist)	0.012			n.a.
Lead compounds (as $PbCl \cdot Br$)	0.002			n.a.

Source: see Appendix B herein
(a) Premium grade fuel
(b) Regular grade fuel

Table 2-9. FUELS CONSUMED FOR TRANSPORTATION IN WESTERN LOUISVILLE - 1956

Fuel	User	Consumption, gallons
Gasoline	Autos, trucks, buses	18,500,000
Diesel fuel	Buses, locomotives	1,200,000

Table 2-10. SUMMARY OF METEOROLOGICAL MEASUREMENTS

Measurement	Where measurements were made*	Duration of Measurements
Wind speed and direction (surface)	Stations 1, 3, 7, 8, 12	Throughout study
Wind speed and direction (524 ft. above ground)	Station 11	Latter part of study
Temperature and relative humidity	Stations 1; 3; 8; 9; 10; 12; 13	Throughout study
Precipitation	Stations 1; 3; 12	Throughout study
Solar radiation	Station 1	May 15, 1957-August 1957
	43rd. and Vermont Streets	June 1956-May 15, 1957
Temperature difference between 6 and 55 feet above ground	Station 1	Latter part of study
Temperatures at 60; 170; and 524 feet above ground	Station 11	Latter part of study
Temperature at various points above ground (using wiresonde)	E. Leland Taylor Park (Near station 1)	Largely in October 1956; some throughout study. Total of 45 wiresonde runs.
Visibility; barometric pressure; sky conditions; sunshine; obstructions to vision	Station 12 (U. S. W. B. station at Standiford Field)	Throughout study.

* Station designations as shown on figure 2-1.

Table 2-11. WINDS USED FOR RUBBERTOWN AND NON-RUBBERTOWN SAMPLING PERIOD DESIGNATIONS

Sampling station	Bearing of Rubbertown area from station (degrees azimuth)	Compass points for "Rubbertown" wind	Compass points for "Non-Rubbertown" wind	Reference wind station
1	204-217	S;SSW;SW	W-N-SE	1
2	290-300	W;WNW;NW;NNW	NNE-S-SW	8
3	007-032	N;NNE;NE	E-S-NW	3
4	169-207	SSE;S;SSW;SW	W-N-ESE	1
5	202-244	S;SSW;SW;WSW	WNW-N-SE	1
6	214-270	SSW;SW;WSW;W	NW-NE-SSE	1

Table 3-1. EMISSION OF POLLUTANTS FROM FUEL BURNING AT DOMESTIC AND COMMERCIAL ESTABLISHMENTS - WESTERN LOUISVILLE - 1956* (EMISSIONS IN TONS PER YEAR)

Pollutant	Total	Fuel		
		Coal	Gas	Oil
Gaseous emissions, total	11,100	10,200	560	325
Sulfur dioxide	7,890	7,850	1	43
Total hydrocarbons	1,850	1,700	115	40
Oxides of nitrogen (as NO_2)	438	27	308	103
Inorganic chlorides (as HC1)	398	398	-	-
Organic acids (as HOAc)	211	-	92	119
Sulfur trioxide	172	166	<1	5
Aldehydes (as CH_3CHO)	57	-	43	14
Flourides (as HF)	40	40	-	-
Hydrogen sulfide	18	18	-	-
Ammonia	1	-	<1	<1
Fine particulate emissions, total	988	986	-	2
Smoke (carbon, tars, metallic oxides)	988	986	-	2
Coarse particulate emissions, total	995	995	-	-
Smoke (carbon, tars)	663	663	-	-
Flyash (SiO_2, Al_2O_3, other oxides)	332	332	-	-

Calculated from tables 2-5; 2-6; and 2-7
Fine particulates are less than 1 μ in size
Course particulates are greater than 1 μ in size
* Includes combustion effluents from a few small industrial plants

Table 3-2. EMISSION OF POLLUTANTS FROM TRANSPORTATION ACTIVITIES - WESTERN LOUISVILLE - 1956 (EMISSIONS IN TONS PER YEAR)

Pollutant	Total	Fuel		
		Gasoline**		Diesel fuel*
		Combustion	Handling	Combustion
Gaseous emissions, total	10,100	8,460	960	647
Total hydrocarbons	8,940	7,540	960	440
Paraffins				
Methene		460		
Ethane		920		
C_3 - C_5 (MW = 58)		960		
C_6 + (MW = 93)		1,040		
Olefins				
C_5 (MW = 70)		1,030		
C_6 (MW = 84)		700		
C_7 + (MW = 100)		920		
Acetylene		350		
Aromatics				
Benzene		120		
Other (MW = 92)		180		
Oxides of nitrogen (as NO_2)	660	520		140
Oxides of sulfur (as SO_2)	318	280		38
Aldehydes (as CH_3CHO)	78	68		10
Organic acids (as CH_3COOH)	56	37		19
Ammonia	19	19		
Fine particulate emissions, total	310	257		53
Carbon (non-ether soluble)	112	59		53
Oils (motor oil mist)	110	110		
Tars (ether soluble)	70	70		
Lead compounds (as $PbCl \cdot Br$)	18	18		

Calculated from tables 2-8 and 2-9

* Includes use by railroad locomotives and buses

** Includes use by automobiles, trucks and buses

Table 3-3. EMISSION OF POLLUTANTS FROM PLANTS NUMBERS 1, 10, 11, 12 AND 13 (PETROLEUM DEPOTS) (EMISSIONS IN TONS PER YEAR)

Source of pollutants	Process losses	
	Emitted as gases or vapors	
	Condensable	
	Aliphatic hydrocarbons (as butane and pentane)*	
Plant No. 1	145	a
Plant No. 10	1,480	a
Plant No. 11	485	a
Plant No. 12	107	a
Plant No. 13	546	b
Total	2,760	SI

* No other emissions of consequence from these plants.

Key:
a. Calculated from modified American Petroleum Institute storage tank loss formula and quantity of material handled. (Appendix B herein).
b. Calculates from material balance (receipts and shipments)
SI Seasonal - intermittent emissions.

Table 3-4. EMISSION OF POLLUTANTS FROM PLANT 2
(WOOD PRESERVING PLANT)
(EMISSIONS IN TONS PER YEAR)

Point of emission (see figure)	Source	Process losses	Products of combustion									
		Emitted as gases and vapors	Emitted as gases and vapors								Emitted as particulates	
		Condensable	Permanent	Condensable			Hygroscopic				Fine (< 1 μ)	Course (> 1 μ)
		Creosote vapor (primarily m-cresol)	Sulfur dioxide	Aldehydes (as acetaldehyde)	Oxides of nitrogen (as NO_2)	Total hydrocarbons	Fluorides (as HF)	Inorganic chlorides (as HCl)	Organic acids (as acetic)	Sulfur trioxide	Smoke (carbon and tars)	Flyash (unburned fuel and inorganic ash)
	Boiling point °C→	203	-10	20	21	variable	19	-85	118	45		
A	Creosote storage	nil a										
B	R. R. ties storage	1,360 b										
C	Coal combustion		157 c		33 c		0.70 c	6.6 c		20 c	0.06 d	28 d
D	Wood combustion		0.7 c	8.1 c	5.8 c	90 c	0.03 c		1.8 c		0.63 d	90 d
	Sub-totals(rounded)	1,360 S	158 C	8.1 C	39 C	90 C	0.73 C	6.6 C	1.8 C	20 C	0.69 C	118 C

Total as gases and vapors - 1,690 tons/yr.
(process losses -(1,360)
(products of combustion -(330)

Total as particulates - 119 tons/yr.
(products of combustion - (119)

Key:
- a. Calculated from modified API storage tank loss formulas and process information (Appendix B)
- b. Calculated from analysis of R. R. tie borings.
- c. Calculated from Table 2-2 and fuel consumption
- d. Calculated from Tables 2-2; 2-3; 2-4 and fuel consumption

C - Primarily a continuous emission

S - Primarily a seasonal emission

Table 3-5. EMISSION OF POLLUTANTS FROM PROCESSING AT PLANT 3
(NEOPRENE PLANT)
(EMISSIONS IN TONS PER YEAR)

Source	Process losses																	
	Emitted as gases and vapors																	
	Permanent							Condensable									Hygroscopic	
	Acetylene	Chlorine	Chlordifluoromethane	Methane	Sulfur dioxide	Trifluoromethane	Vinylchloride (VC)	Aldehydes (as acetaldehyde)	Chloroform	Chloroprene (CD)	1, 3 Dichlorobutane-2 (DC)	Divinylacetylene DVA	Methanol	Monovinylacetylene (MVA)	Pentene-1	Toluene	Hydrogen chloride	Sulfur trioxide
Boiling point ° C	-84	-35	-41	-1	-10	-82	-12	20	61	59	119	85	65	6	30	111	-85	45
MVA AREA	204			7.8 a				0.3 c		1.0 c		17 c	4.0 a	54 b, c		5 a, c	409 C	
CD AREA	15 a						170 a	52 b		66 b, d, e	7.5 b, d, e,			252 a, b, e		1 d	10 a, b,	
POLY AREA	1.4 a									679 a d					630 a	1990 a		
ACID AREA	See table for combustion products emissions from plant	49 b			15 b	103 b											1979 b	33 b
FREON AREA			50 b			18 b			10 d									
MISC. AREA	See table for combustion products from plant 3												4.4 f			1 d		
Sub-totals (rounded)	221 C	49 C	50 C	8 C	15 C	120 C	170 C	52 I	10 SI	750 C	8 SI	17 C	8 SI	310 C	630 C	1900 C	2400 C	33 C

Key:

a - Calculated from analysis of 2-liter grab samples and process information
b - Estimated from material balance and process loss information supplied by company
c - Estimated from material balances and process loss information and assuming 99.9% combustion efficiency
d - Calculated from modified API storage tank loss formulas and process information (Appendix B herein)
e - Calculated from modified API storage tank loss formulas and process information with boiling losses estimated using heat balances and Raoult's law.
f - Calculated from process data, Weather Bureau data, and mass transfer theory (Appendix B herein)
C - Primarily a continuous emission
I - Primarily an intermittent emission
S - Primarily a seasonal emission

Table 3-6. EMISSION OF POLLUTANTS FROM COMBUSTION OPERATIONS AT PLANT 3 (NEOPRENE PLANT)

(EMISSIONS IN TONS PER YEAR)

Source	Products of combustion										
	Emitted as gases and vapors									Emitted as particulates	
	Permanent		Condensable			Hygroscopic				Fine (<1 μ)	Coarse (>1 μ)
	Ammonia	Sulfur dioxide	Aldehydes (as acetaldehyde)	Oxides of nitrogen (as NO_2)	Total hydrocarbons	Fluorides (as HF)	Inorganic chlorides (as HCl)	Organic acids (as acetic)	Sulfur trioxide	"Flyash" (unburned fuel and inorg. ash)	"Flyash" (unburned fuel and inorg.ash)
Boiling point °C	-33	-10	°0	°1	variable	19	-85	118	45		
ACID AREA Nat.gas combustion	5.7 a	17 a	324 a	4380 a		a		1050 a			
MISC AREAS Power house stacks		10380 a		1956 a		41 a	391 a		1320 a	16 b	3230 b
Incinerator-trash	0.0 a	0.5 a	6.5 a	4.7 a	72 a	0.0 a		1.4 a		0.1 c	9.3 c
Incinerator-fuel	0.0 a	0.0 a	0.4 a	4.9 a	1.5 a			1.2 a			
Sub-totals(rounded)	5.7 C	10400 C	330 C	6340 C	73 C	41 C	391 C	1050 C	1320 C	16 C	3240 C

Summary of emissions from plant 3

Total as gases and vapors - 26,700 tons/yr.
(process losses) - (6,850)
(products of comb..) - (19,900)

Total as particulates - 3,260 tons/yr.
(products of comb.) (3,260)

Key:
a. Calculated from table 2-2 and fuel consumption
b. Calculated from effluent data supplied by company, tables 2-3 and 2-4 and cyclone performance theory.
c. Calculated from tables 2-3 and 2-4 and fuel consumption.

C - Primarily a continuous emission
I - Primarily an intermittent emission
S - Primarily a season emission

TABLE 3-7
Emission of Pollutants from Plant 4
(Synthetic rubber plant)
(Emission data in tons per year)

Source		Process losses															Emitted as Particulates	
		Emitted as gases and vapors																
		Permanent				Condensable											Fine (<1μ)	Course (> 1μ)
Point of emission (see figures)	(Numbers after source names are plant equipment identifications)	Acetylene	1, 3-Butadiene	2-Methyl propene	Vinyl chloride	Acrylonitrile	1, 3-Butadiyne	1-Butyne	3, 4-Dimethylheptane	Ethanenitrile	n-Heptane (C_7H_{16})	Octylene (C_8H_{16})	Oxides of nitrogen (as NO_2)	1, 4-Pentadiene	cis-2-Pentene	Propenal	Butadiene-copolymers and vinyl chloride resins	Butadiene copolymers and vinyl chloride resins
	Boiling point °C-→	-84	-4	-6	-12	78	10	9	132	82	90	126	21	26				
	SYNTHETIC RUBBER PROCESS																	
A1	Poly kettle vacuum jets		20 a			45 a												
2	Blow down tank vents (1-6)		310 a	33 a		9.8a		31 a										
3	Blow down tank vents (7-12)		62 a	38 a		9.4a		4.5a										
4	Blend tank vents (21. 22)*		13 a		0.7 a	6.1a	1.6a			3.5 a				5.4 a		13 a		
5	Blend tank vents (23, 24)*		6.8a			4.0a	0.8a			1.8 a				2.7 a		0.7a		
6	Barometric condenser vents		0.2a	8.7 a		125 a		0.2a										
B1	Blend tank vents*		15 a			7.0a	1.9a			4.1 a				6.2 a		15 a		
2	Steel tank vents*		2.1a			1.1a	0.3a			0.6 a				1.0 a		2.4a		
C1	Coagulator		12. a	99 a		3.6a	16 a											
D1	Coagulation tanks		1.3a	1.0 a		0.4a	1.6a											
2	Drier vents		55 a						54 a						29 a			
E-	Process dust																See below (E)	
	VINYL CHLORIDE RESIN PROCESS																	
A1	Gas recovery vent (1, 2)*	77 a			230 a								0.9 a					
B1	Blend tanks (Plant 2-1)				19 a													
2	Blend tanks (Plant 2-15)				7.7a													
C1	Dryer-rotoclone (2-1)				98 a													
2	Dryer-rotoclone (2-15)				12 a													
3	Dryer-"Aerodyne"(disp.)(2-15)				35 a													
4	Dryer-bag collector (2-1)				9.7a													
5	Dryer-bag collector (vent.)(1-112)				220 a													
6	Dryer-bag collector (disp.)(1-112)				180 a													
D1	Rolling mills (2-8)				320 a													
E-	Process dust										1170 a	880 a					0.1 d	27 d
	Sub-totals (rounded)	77 C	500 I	180 C	1140 C	210 C	22 C	36 I	54 C	10 C	1170C	880 C	0.9 C	15 C	29 C	31 C	0.1 C	27 C

Source	Products of combustion								
	Emitted as gases and vapors							Emitted as particulates	
	Permanent	Condensable		Hygroscopic				Fine (< 1μ)	Course (> 1μ)
	Sulfur dioxide	Aldehydes (as acetaldehyde)	Oxides of nitrogen (as NO_2)	Fluorides (as HF)	Inorganic chlorides (as HC1)	Organic acids(as acetic)	Sulfur trioxide	"Flyash" (unburned fuel & inorganic ash)	"Flyash" (unburned fuel & inorganic ash)
Boiling point °C	-10	20	21	19	-85	118	45		
Coal combustion	2920 b	92 b	510 b	10 b	100 b	770 b	370 b	0.9 c	460 c
Sub-totals	2920 C	92 C	510 C	10 C	100 C	770 C	370 C	0.9 C	460 C

Total as gases and vapors - tons/yr. 9150
(process losses) - (4, 350)
(products of combustion - (4, 800)

Total as particulates - 490 tons/yr.
(process losses) - (27)
(products of combustion) - (460)

Key:
a. Calculated from analysis of 2-Liter grab samples and process information
b. Calculated from table 2-2 and fuel consumption
c. Calculated from tables 2-3 and 2-4 and fuel consumption
d. Estimated from process loss information supplied by company

C - Primarily a continuous emission
I - Primarily an intermittent emission
* - Minor emissions of certain materials not listed herein

Table 3-8. EMISSION OF POLLUTANTS FROM PLANT 5
(OIL REFINERY)
(EMISSIONS IN TONS PER YEAR)

Point of emission (see figures) Source	Process Losses																		Products of combustion															
	Emitted as gases and vapors														Emitted as particulates				Emitted as Gases and Vapors														Emitted as particulates	
	Permanent				Condensable										Fine (<1μ)		Course (>1μ)		Permanent				Condensable						Hygroscopic				Fine (<1μ)	
	Ammonia		Sulfur dioxide		Aldehydes (as acet-aldehyde)		Cyanides (as HCN)		Oxides of nitrogen (as NO_2)		Total hydro-carbons				Aluminum silicates		Aluminum silicates		Amonia		Sulfur dioxide		Aldehydes (as acet-aldehyde)		Oxides of nitrogen (as NO_2)		Total hydro-carbons		Organic acids (as acetic)		Sulfur trioxide		"Smoke" (tars and metallic oxide fume)	
Boiling point °C ⟶	-33		-10		20		26		21		variable								-33		-10		20		26		variable		118		45			
STORAGE TANKS																																		
A1 Breathing loss											410	a																						
2 Filling loss											395	a																						
LOADING FACILITIES																																		
B1 Barges											86	a																						
2 Trucks											109	a																						
3 Tank cars											13	a																						
REFINING PROCESS																																		
C1 Equip. leakage											72	b																						
2 Equip. maintenance											8.4	b																						
3 Vacuum jets											6.5	b																						
4 Cooling towers											5.0	c																						
5 Waste water separators											262	b																						
6 Compressor engines																			3.5	b			2.8	b	14	b	22	b						
a. Refinery fuel gas																			0.2	c	*660	d	8.7	c	110	c			6.7	c	*20	d	9.8	c
b. Refinery fuel oil																			0.1	c	*144	d	0.9	c	68	c			16	c	* 4.3	d	20.	c
8 H_2S scrubber			320	e																														
9 Gasoline treaters			61	e																														
10 Cat. cracker regen. stacks	32	c			16	c	0.1	c	37	c	129	c			0.02	f	69	f																
Sub-totals (rounded)	32	C	381	C	16	C	0.1	C	37	C	1550	SI			0.02	C	69	C	3.8	C	804	C	12	C	192	C	22	C	23	C	24	C	30	C

Total as gases and vapors - 3100 tons/yr.
(process losses) - (2,020)
(prod's. of combustion (1,080)

Total as particulates - 99 tons/yr.
(process losses) - (69)
(prod's. of combustion (30)

Key:
a. Calculated from modified API storage tank loss formulas and process information
b. Estimated from refinery throughout and factors in table 2-1
c. Estimated from process information and factors in table 2-1
d. Calculated from sulfur balance on crude throughout and refined products using process information supplied by company, and from data of table 2-1
e. Estimated from material balances and process loss information supplied by company
f. Calculated from process information, factors in table 2-1, and particle size estimate based on experience in San Francisco (see ref. 14)

C - Primarily a continuous emission
I - Primarily an intermittent emission
S - Primarily a seasonal emission
* - Includes sulfur gases from catalyst regenerator stacks

Table 3-9. EMISSION OF POLLUTANTS FROM PLANTS 6 AND 7
(COAL FIRED STEAM-ELECTRIC GENERATING PLANTS)
(EMISSIONS IN TONS PER YEAR)

Source	Products of combustion						
	Emitted as gases and vapors					Emitted as particulates	
	Per-manent	Condens-able	Hygroscopic			Fine (<1 µ)	Course (>1 µ)
	Sulfur dioxide	Oxides of nitrogen (as NO_2)	Fluorides (as HF)	Inorganic chlorides (as HC1)	Sulfur trioxide	"Flyash" (primarily inorganic ash)	"Flyash" (primarily inorganic ash)
Boiling point °C ⟶	-10	21	19	-85	45		
PLANT NO. 6 Coal combustion	32000 a	4580 a	97 a	918 a	4060 a	185 b	1660 b
PLANT NO. 7 Coal combustion	34900 a	5040 a	106 a	1010 a	4400 a	203 b	1820 b
Sub-totals (rounded)	66900 C	9620 C	203 C	1930 C	8460 C	388 C	3480 C

Totas as gases and vapors - 87,100 tons/yr.

Total as particulates - 3,870 tons/yr.

Key:
a. Calculated from table 2-2 and fuel consumption
b. Calculated from table 2-3 and 2-4, fuel consumption, and electrostatic precipitator performance theory
C - Primarily a continuous emission

Table 3-10. EMISSION OF POLLUTANTS FROM PLANT 8
(CALCIUM CARBIDE-ACETYLENE PLANT)
(EMISSIONS IN TONS PER YEAR)

Source		Process losses								Products of Combustion							
Point of emission (see figure)		Emitted as gases and vapors				Emitted as particulates				Emitted as gases and vapors						Emitted as particulates	
		Permanent			Hygro-scopic	Fine (< 1μ)	Course (> 1μ)	P ermanent		Condensable		Hydroscopic				Fine (< 1μ)	Course (> 1μ)
		Acetylene	Hydrogen sulfide	Sulfur dioxide	Sulfur trioxide	Primarily calcium carbonate	Primarily calcium carbonate	Hydrogen sulfide	Sulfur dioxide	Aldehydes (as acet-aldehyde)	Oxides of nitro-gen (as NO_2)	Fluorides (as HF)	Inor-ganic chlorides (as HC1)	Organic acids(as (acetic)	Sulfer trioxide	"Flyash" (primari-ly inor-ganic asn)	"Flyash" (primari-ly inor-ganic asn)
	Boiling point °C	-84	-60	-10	45			-60	-10	20	21	19	-85	118	45		
	CALCIUM CARBIDE PROCESS																
A1	Coke drier stacks			*83 a	155 a	0.0 f	147 f	0.2 d			14 d	0.2 d	2.9 d	n.a.			
2	Elec. furnace stacks					0.0 f	1340 f										
3	Furnace room vents	1370 b				0.0 f	2000 f										
4	Main stack			*1440 a	60 a	30	1520 f										
	ACETYLENE PROCESS																
B1	Hopper purging**	284 b	0.1 c														
2	Slurry pit and tail's pond	541 g	44 e														
	PILOT PLANT																
C	Stack			112 a	8.5 a	0.1 f	117 f	n.a.		6.8 d	49 d	n.a.	n.a.	56 d			
	STEAM PLANT																
D	Stacks (coal)							0.0 d	24 d		4.2d	0.1 d	0.8 d		3.2 d	0.0 h	15 h
	Sub-totals (rounded)	2195 C	44 C	1630 C	224 I	30 C	5124 C	0.2 I	24 SC	6.8 I	67 I	0.3 I	3.7 I	56 I	3.2 SC	0.0 SC	15 SC

Total as gases and vapors - 4,280 tons/yr.
(process losses) - (4,090)
(products combustion) - (150)

Total as particulates - 5,139 tons/yr.
(process losses) - (5,124)
(products of combustion) - (15)

Key:
- a. Calculated from samples using bubblers and method of Johnstone (see references 4 and 5)
- b. Calculated from analysis of 2-liter grab samples and process information
- c. Estimated from product analysis supplied by company and process information
- d. Calculated from table 2-2 and fuel consumption
- e. Calculated from analysis of freeze-out samples and process information
- f. Calculated from stack samples and size frequency analysis determined microscopically
- g. Calculated from analysis of slurry and process information
- h. Calculated from tables 2-3 and 2-4 and fuel consumption

n.a. - Data not available
C - Primarily a continuous emission
I - Primarily an intermittent emission
S - Primarily a seasonal emission
* - Includes sulfur gases from fuel combustion
** - Minor emission of certain materials not listed herein

Table 3-11. EMISSION OF POLLUTANTS FROM PLANT 9
(PRODUCTION OF HYDROCHLORIC ACID; PERCHLORETHYLENE; AND CARBON TETRACHLORIDE)
(EMISSIONS IN TONS PER YEAR)

Source		Process losses				Products of combustion						
Point of emission (see figure)		Emitted as gases and vapors				Emitted as gases and vapors					Emitted as particulates	
		Permanent	Condensable		Hygroscopic	Permanent	Condensable	Hygroscopic			Fine (<1 µ)	Course (>1 µ)
		Chlorine	Carbon tetrachloride	Perchloroethylene	Hydrogen chloride	Sulfur Dioxide	Oxides of nitrogen (as NO_2)	Fluorides (as HF)	Inorganic chlorides (as HC1)	Sulfur trioxide	"Flyash" (unburned fuel and inorganic ash)	"Flyash" (unburned fuel and inorganic ash)
	Boiling point ° C ⟶	-35	77	121	-85	-10	21	19	-85	45		
	PROCESS VENT SCRUBBER											
A1	Cl_2 barge sniff gas removal and process waste		47.0 a									
2	Cl_2 barge transfer to storage	5.9 a	136 a									
3	Cl_2 storage tank pressure release and process waste	0.7 a	27 a									
B-	Perchloroethylene receiver*											
	PERCHLOROETHYLENE STORAGE											
C1	Filling loss			1.2 b								
2	Breathing loss			0.7 b								
	CARBON TET. STORAGE											
D1	Filling loss		16 b									
2	Breathing loss		9.7 b									
	STORAGE WAREHOUSE											
E-	Drumming operation		3.6 a	51 a								
F-	Acid vent scrubber	4.0 d			13 d							
	POWER PLANT											
G-	Coal combustion					684 c	120 c	2.4 c	24 c	87 c	0.9 e	435 e
	Sub-totals (rounded)	11 I	240 I	53 I	13 C	684 C	120 C	2. C	24 C	87 C	0.9 C	435 C

Total as gases and vapors - 1240 tons/yr.
(process losses) - (320)
(products of combustion) - (920)

Total as particulates - 436 tons/yr.
(process losses) - (0)
(products of combustion) - (436)

Key: a. Calculated from analysis of 2-liter grab samples and process information
b. Calculated from modified API storage tank loss formulas and process information
c. Calculated from table 2-2 and fuel consumption
d. Calculated from emission analysis supplied by company
e. Calculated from tables 2-3 and 2-4 and fuel consumption

C- Primarily a continuous emission
I - Primarily an intermittent emission
* - Data not available

Table 3-12. COMPARATIVE CLIMATOLOGICAL DATA

Month	Monthly degree days			Precipitation			Snowfall			Number of days of 0.01 inch or more precipitation		
	Normal	1956	1957	Normal	1956	1957	Normal	1956	1957	84-year average	1956	1957
Jan	933	999	1016	4.10	2.87	2.83	4.1	9.8	3.2	12	11	16
Feb	802	680	644	3.11	8.34	2.83	3.5	1.2	T	10	16	10
Mar	611	584	618	4.67	4.50	1.66	2.1	1.6	0.4	12	12	16
Apr	285	348	264	4.01	2.63	6.09	0.2	T	0.2	12	14	15
May	94	90	86	3.93	3.98	5.78	T	0	0	11	11	12
Jun	5	30	0	4.06	2.38	6.57	0	0	0	11	11	15
Jul	0	0	0	3.08	2.59	4.28	0	0	0	10	10	7
Aug	0	4	0	3.06	4.03	1.01	0	0	0	9	10	6
Sep	51	63	-	2.70	3.70	-	0	0	-	8	9	-
Oct	232	131	-	2.45	1.74	-	0.1	0	-	8	7	-
Nov	579	624	-	3.12	1.52	-	0.5	1.2	-	9	7	-
Dec	871	624	-	3.30	2.74	-	3.0	T	-	11	11	-

Month	Percent of possible sunshine			Average hourly wind speed				Percent frequency of hourly winds ≤7 mph		
	56-year average	1946	1957	84-year average	5-year average	1956	1957	5-year average	1956	1957
Jan	41	54	37	9.9	10.7	10.0	10.5	31	34	30
Feb	47	41	35	10.3	9.8	10.9	10.1	37	27	33
Mar	52	58	56	10.8	10.5	12.2	10.9	33	24	27
Apr	57	58°	52	10.1	10.2	12.1	10.8	33	27	28
May	64	59	70	8.5	7.6	10.0	9.9	56	31	35
Jun	69	70	57	7.7	7.0	7.1	9.0	60	57	41
Jul	73	75	71	7.0	6.5	7.7	6.6	65	53	65
Aug	69	76	81	6.6	5.6	7.6	6.5	72	52	63
Sep	68	84	-	7.1	6.4	7.8	-	64	50	-
Oct	65	70	-	7.8	6.9	6.9	-	60	59	-
Nov	51	57	-	9.4	9.8	10.3	-	39	37	-
Dec	39	34	-	8.9	9.0	10.7	-	44	29	-

Table 3-13. MONTHLY CLIMATOLOGICAL STATISTICS FOR NETWORK STATIONS

Month	Median wind speed (m.p.h.)						Total precipitation (in.)			Average daily solar radiation (cal/cm^2)
Station	#1	#3	#7	#8	#11	#12	#1	#3	#12	#1
1956 Jan	6.-	-	-	-	-	9.6	-	-	2.87	-
Feb	6.8	-	-	-	-	10.3	-	-	8.34	-
Mar	7.4	-	-	-	-	11.3	-	-	4.50	-
Apr	7.6	8.5	6.2	10.4	-	11.4	-	-	2.63	-
May	6.3	6.9	5.0	8.2	-	9.3	-	-	3.98	-
Jun	5.0	4.2	2.4	5.5	-	6.3	4.10	-	2.38	-
Jul	4.8	4.7	2.5	5.6	6.9	6.7	4.23	-	2.59	476
Aug	4.7	4.2	2.5	5.6	8.6	6.8	3.51	3.36	4.03	457
Sep	3.7	4.0	2.6	5.9	11.2	7.0	2.31	2.14	3.70	399
Oct	3.3	4.0	2.0	5.5	8.4	6.0	2.34	1.82	1.74	266
Nov	6.8	7.0	3.4	7.8	13.4	9.4	1.41	1.39	1.52	176
Dec	7.0	7.0	3.4	7.7	13.2	10.3	3.08	-	2.74	111
1957 Jan	6.3	5.7	3.1	6.9	12.2	9.9	2.90	-	2.83	111
Feb	5.4	6.1	2.6	7.1	-	9.3	4.19	3.01	2.83	178
Mar	6.0	6.7	2.4	8.1	12.3	10.4	1.64	1.96	1.66	318
Apr	6.4	-	-	-	-	10.0	6.04	5.66	6.09	-
May	6.4	-	-	-	-	9.0	6.66	6.94	5.78	-
Jun	5.7	-	-	-	-	8.2	7.67	7.59	6.57	-
Jul	4.6	-	-	-	-	5.5	3.90	3.18	4.28	-

Table 3-14. MONTHLY MEAN TEMPERATURES FOR NETWORK STATIONS (TEMPERATURES IN DEGREES F.)

Month		Standiford Field #12)			E. Leland Taylor (#1)			Senn Site (#3)			Gulf Site (#8)		
		Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1956	Jan	40.3	24.7	32.5									
	Feb	48.9	33.7	41.3	48.8	33.2	41.0						
	Mar	56.7	35.5	46.1	56.1	34.8	45.4						
	Apr	64.2	43.7	54.0	63.4	42.7	53.1	63.2	39.8	51.5			
	May	76.1	55.2	65.7	76.6	55.4	66.0	76.8	52.9	64.8	76.4	55.1	65.8
	Jun	84.9	62.9	73.9	84.9	62.0	73.4	84.7	58.7	71.7	85.6	62.1	73.8
	Jul	86.5	67.2	76.9	86.4	66.6	76.5	86.6	63.2	74.9	87.2	66.7	76.9
	Aug	85.4	64.9	75.2	86.2	64.1	75.1	86.3	61.1	73.7	86.6	64.1	75.4
	Sep	78.1	54.3	66.2	79.8	53.4	66.6	79.6	50.0	64.8	79.8	54.1	67.0
	Oct	72.6	49.5	61.1	73.7	48.2	60.9	73.4	46.0	59.7	73.5	49.8	61.7
	Nov	54.4	33.5	44.0	54.6	33.6	44.1	54.4	30.9	42.7	54.4	34.5	44.5
	Dec	52.1	37.3	44.7	51.8	36.1	43.9						
1957	Jan	39.4	24.6	32.0	37.9	22.4	30.2						
	Feb	49.4	33.5	41.7	50.1	32.5	41.3	49.4	31.4	40.4	49.5	32.9	41.2
	Mar	54.1	35.7	44.9	54.5	35.4	44.9	53.6	33.6	43.6	54.0	34.7	44.4
	Apr	69.4	48.8	59.1	69.6	46.9	58.3						
	May	77.4	55.0	66.2	77.5	54.3	65.9						
	Jun	83.3	66.2	74.8									
	Jul	87.1	68.0	77.6									

		River Site(#9)			Iroquois Park (#10)			Silver Hills (#13)		
1956	Jan									
	Feb									
	Mar									
	Apr									
	May	77.6	54.8	66.2						
	Jun	85.0	60.8	72.9	83.4	62.6	73.0			
	Jul	86.9	65.6	76.2	85.0	66.3	75.6			
	Aug	87.0	63.9	75.5	84.3	64.6	74.5	86.8	64.4	75.6
	Sep	80.0	53.8	66.9	78.2	54.4	66.3	80.6	55.8	68.2
	Oct	73.8	49.3	61.5	72.3	51.1	61.7	74.1	52.1	63.1
	Nov	54.3	34.4	44.3	53.1	34.7	43.9	54.6	35.3	45.0
1957	Jan	50.4	35.2	42.8	48.6	33.0	40.8	48.3	3	
	Feb	50.4	35.2	42.8	48.6	33.0	40.8	48.3	32.7	40.5
	Mar	55.8	36.4	46.1	52.9	35.5	44.2	53.8	35.4	44.6

Station month with 5 or more days missing record not tabulated. Days of missing record estimated by subtracting monthly average difference between Airport value and station value and station value from Airport value.

Table 3-15. COMPARISON OF CONCURRENT VISIBILITIES AT 4000 MICHIGAN DRIVE (STATION A-WEST END) WITH WEATHER BUREAU AIRPORT STATION

MARCH - AUGUST 1957; 0800 LOCAL TIME

	No. of days on which visibility was stated distance (in miles)							
	<1	1-1 7/8	2-2 1/2	3	4	5	6	≥ 7
4000 Michigan Dr.	4	21	21	7	16	16	10	13
Airport	1	1	4	8	4	9	6	75

Table 3-16 - Part A. TOTAL WEIGHT OF SUSPENDED PARTICULATE MATTER: BY STATION, SAMPLING PERIOD, AND MONTH

Number of samples represented is given in part B of this table.

Sampling station	Sampling period*	Season ratio Jan '57 July '56	Total particulate concentration (Monthly mean conc. in micrograms per cubic meter of air)																	
			Apr '56-Mar '57 mean	1956												1957				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total for Western Louisville 1, 4, 5, &6	All	1.12	119	155	134	164	138	140	134	101	118	127	142	113	99	113	102	114	130	118
	1	1.16	105	154	135	160	133	133	109	88	102	109	112	98	84	102	96	111	120	98
	2	1.23	106	152	120	153	121	125	119	88	106	110	115	96	98	108	97	99	114	109
	3	1.00	146	160	146	179	160	163	173	128	145	162	199	145	114	128	112	132	157	148
1	All	1.05	122	155	134	156	137	139	139	106	116	135	139	106	100	111	108	123	144	124
	1	1.00	111	154	135	158	132	131	106	99	109	132	115	104	84	99	104	116	135	96
	2	1.15	106	152	120	144	127	119	115	92	106	114	108	89	99	106	97	99	116	100
	3	1.01	149	160	146	167	152	168	197	28	134	159	194	125	118	129	123	153	182	176
2	All	1.00	134		138	143	156	168	156	113	128	144	164	114	107	113	115	130	147	107
	1	0.98	122		113	136	168	130	141	103	119	136	147	101	92	101	107	123	129	80
	2	1.12	118		129	116	115	181	139	104	115	123	124	88	96	116	112	107	135	108
	3	0.92	161		167	178	186	193	189	132	150	172	221	152	133	122	126	160	178	134
3	All	1.22	93				95	88	84	76	94	108	131	83	79	93	90	98	98	100
	1	1.44	97				99	95	76	61	95	105	142	94	77	88	106	124	111	95
	2	1.20	91				92	77	82	80	96	122	127	79	76	96	82	86	83	96
	3	1.12	92				94	92	93	86	92	98	125	76	83	96	82	83	99	110
4	All	1.32	98					129	110	78	85	90	124	109	85	103	85	98	113	107
	1	1.56	88					134	92	64	76	69	108	96	76	100	82	98	103	94
	2	1.53	93					134	110	64	87	89	116	101	75	98	81	87	107	109
	3	1.06	113					118	127	105	91	112	148	131	103	111	91	109	130	118
5	All	1.03	126			192	138	149	133	109	135	152	163	112	100	112	99	108	120	96
	1	0.84	115			167	134	136	117	107	132	148	134	96	84	90	89	107	115	78
	2	1.20	108			185	113	122	110	90	119	121	133	92	100	108	93	90	104	83
	3	1.06	155			220	167	188	172	129	155	186	223	148	116	137	114	127	142	127
6	All	1.12	127					138	152	111	135	132	142	123	110	124	115	126	143	146
	1	1.46	102					127	122	81	93	88	93	94	94	118	107	122	126	122
	2	1.13	116					148	140	104	114	118	104	101	116	118	117	119	129	145
	3	0.91	165					138	195	149	198	190	230	175	119	136	122	138	175	171

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

Table 3-16 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SAMPLERS; BY STATION, SAMPLING PERIOD, AND MONTH

Values obtained are given in part A of this table.

Sampling station	Sampling period *	Apr '56 Mar'57	Number of samples																
			1956												1957				
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total for Western Louisville 1, 4, 5 & 6	All	4070	57	87	119	180	259	360	372	368	357	372	359	371	367	334	371	358	368
	1	1354	20	29	39	60	86	120	124	122	119	124	120	124	122	110	123	118	121
	2	1358	21	29	40	60	86	120	124	123	119	124	119	124	123	112	124	120	123
	3	1358	16	29	40	60	87	120	124	123	119	124	120	123	122	112	124	120	124
1	All	1088	57	87	93	90	93	90	93	91	88	93	90	93	90	84	93	90	93
	1	362	20	29	31	30	31	30	31	29	330	31	30	31	30	28	31	30	31
	2	364	21	29	31	30	31	30	31	31	29	31	30	31	31	28	31	30	31
	3	362	16	29	31	30	31	30	31	31	29	31	30	31	29	28	31	30	31
2	All	1089		47	93	90	93	90	93	93	90	92	86	93	92	84	93	87	92
	1	361		14	31	30	31	30	31	31	30	30	27	31	31	28	31	29	31
	2	364		16	31	30	31	30	31	31	30	31	29	31	31	28	31	30	30
	3	364		17	31	30	31	30	31	31	30	31	30	31	30	28	31	28	31
3	All	1086				90	93	90	93	93	89	93	88	93	88	84	92	90	90
	1	360				30	31	30	31	31	29	31	29	31	29	28	30	30	31
	2	363				30	31	30	31	31	30	31	30	31	29	28	31	30	29
	3	363				30	31	30	31	31	30	31	29	31	30	28	31	30	30
4	All	958					51	90	93	92	89	93	90	92	91	84	93	89	90
	1	319					17	30	31	31	29	31	30	31	30	28	31	29	29
	2	320					17	30	31	31	30	31	30	31	30	28	31	30	30
	3	319					17	30	31	30	30	31	30	30	31	28	31	30	31
5	All	1093			26	90	93	90	93	92	90	93	90	93	93	83	93	89	92
	1	364			8	30	31	30	31	31	30	31	30	31	31	27	31	29	30
	2	364			9	30	31	30	31	30	30	31	30	31	31	28	31	30	31
	3	365			9	30	31	30	31	31	30	31	30	31	31	28	31	30	31
6	All	931					22	90	93	93	90	93	89	93	93	83	92	90	93
	1	309					7	30	31	31	30	31	30	31	31	27	30	30	31
	2	310					7	30	31	31	30	31	29	31	31	28	31	30	31
	3	312					8	30	31	31	30	31	30	31	31	28	31	30	31

* Sampling periods: 1-2400 to 0800; 2-0800 to 1600; 3-1600 to 2400

Table 3-17 - Part A. TOTAL WEIGHT OF SUSPENDED PARTICULATE MATTER; BY STATION, SAMPLING PERIOD, SEASON AND WIND DIRECTION

Number of samples represented is given in part B of this table

Sampling station	Sampling period*	Wind ratio** $\frac{R}{NR}$ (Apr '56-Mar '57)	Total particulate concentration (mean conc. in micrograms per cubic meter of air)																			
			Total Apr '56-Mar '57				Apr May Jun '56				Jul Aug Sep '56				Oct Nov Dec '56				Jan Feb Mar '57			
			Wind**				Wind				Wind				Wind				Wind			
			All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5,&6)	All	1.31	118	143	109	120	138	170	122	135	115	148	97	111	117	120	114	117	110	139	103	118
	1	1.49	105	128	86	108	125	178	98	122	100	128	80	98	98	108	97	95	103	118	89	110
	2	1.19	106	129	108	103	121	145	103	126	101	128	87	99	102	117	102	96	101	150	86	104
	3	1.29	145	167	129	144	169	193	170	159	144	191	122	138	150	131	131	140	125	148	103	133
1	All	1.39	122	149	107	125	142	167	129	138	119	176	99	115	115	116	107	120	114	137	94	126
	1	1.64	111	146	89	117	133	190	96	124	113	160	82	116	101	119	89	104	107	109	89	121
	2	1.45	106	136	94	107	120	129	104	131	104	154	95	99	99	120	91	95	101	203	86	105
	3	1.13	149	160	141	151	172	182	193	158	140	214	118	135	146	109	148	157	136	141	108	151
2	All	.82	133	97	119	142	156	114	145	168	128	111	127	130	129	83	118	142	119	80	103	130
	1	.83	122	92	111	133	146	126	133	159	119	137	112	124	113	77	100	129	110	79	92	123
	2	.70	115	81	116	119	131	91	126	142	114	96	114	115	103	10	112	100	111	72	112	118
	3	.78	162	118	151	169	190	159	179	196	151	129	154	150	169	114	142	188	137	93	107	146
3	All	1.75	93	135	77	102	89	126	78	93	93	136	79	101	98	155	70	117	94	123	81	97
	1	1.86	97	154	83	98	90	147	96	81	87	133	69	95	105	172	73	119	106	140	105	104
	2	1.84	91	129	70	105	83	101	63	101	99	134	83	112	94	150	51	120	88	104	74	94
	3	1.68	92	131	78	99	93	125	81	99	92	155	83	98	95	129	76	112	87	128	67	92
4	All	1.39	98	128	92	98	117	151	115	108	84	92	78	85	106	119	101	103	96	152	76	98
	1	1.39	89	104	75	93	107	162	87	110	70	78	58	74	93	104	87	93	93	143	75	97
	2	1.39	93	115	83	93	119	128	105	124	80	94	70	82	97	112	100	87	89	147	72	90
	3	1.31	113	141	108	110	124	162	153	108	102	114	101	100	127	145	118	106	104	170	82	105
5	All	1.32	125	156	118	126	139	183	113	140	131	179	104	121	125	130	128	122	107	130	128	122
	1	1.58	115	153	91	111	129	183	98	126	128	189	96	116	105	112	118	95	96	108	81	105
	2	1.46	108	136	93	105	115	158	90	115	110	135	93	106	108	121	116	98	97	136	79	102
	3	1.39	155	183	132	157	182	210	153	176	154	206	125	142	163	136	79	102	127	144	99	137
6	All	1.10	126	134	122	132	150	150	140	152	126	140	110	126	122	113	126	123	122	134	114	125
	1	.92	102	95	103	111	123	114	119	126	88	91	85	87	94	94	101	91	116	107	113	118
	2	1.39	115	128	93	105	142	147	141	139	112	126	92	114	106	114	103	104	118	148	107	119
	3	1.30	162	171	132	157	183	178	170	187	179	202	152	180	165	131	180	170	132	133	122	136

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown toward the station

NR - Wind blowing from directions other than Rubbertown

M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-17 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SAMPLERS; BY STATION, SAMPLING PERIOD, SEASON, AND WIND DIRECTION

Values obtained are given in Part A of this table.

Sampling station	Sampling period*	Number of samples																			
		Total, Apr '56-Mar '57				Apr, May, Jun '56				Jul, Aug, Sep '56				Oct, Nov, Dec '56				Jan, Feb, Mar '57			
		Wind**				Wind				Wind				Wind				Wind			
		All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5 & 6)	All	4074	665	1226	2183	799	114	237	448	1100	230	331	539	1102	237	300	565	1073	84	358	631
	1	1358	225	427	706	266	35	77	154	369	85	111	172	368	74	107	187	356	31	132	193
	2	1358	226	410	722	267	42	86	138	366	69	102	195	367	87	101	179	359	28	121	210
	3	1358	214	389	755	267	37	97	156	366	76	118	172	367	76	92	199	358	25	105	228
1	All	1089	145	364	580	273	36	94	143	272	40	87	145	276	52	83	141	268	17	100	151
	1	363	54	130	179	91	12	31	48	90	17	30	43	92	17	32	43	90	8	37	45
	2	364	43	117	204	91	12	34	45	91	10	24	57	92	18	26	48	90	3	33	54
2	All	1089	68	359	662	273	18	99	156	276	7	98	171	271	22	94	155	269	21	68	180
	1	361	25	126	210	91	6	37	48	92	1	35	56	88	11	27	50	90	7	27	56
	2	364	28	125	211	91	9	32	50	92	4	30	58	91	6	37	48	90	9	26	55
	3	364	15	108	241	91	3	39	58	92	2	33	57	92	5	30	57	89	5	15	69
3	All	1086	73	450	563	273	13	110	150	275	15	130	130	274	29	133	112	264	16	77	171
	1	360	27	133	200	91	5	31	55	91	5	37	49	91	12	42	37	87	5	33	59
	2	363	29	167	167	91	4	43	44	92	8	48	36	92	11	46	35	88	6	30	52
	3	363	17	150	196	91	4	36	51	92	2	45	45	91	6	45	40	89	5	24	60
4	All	958	135	294	529	141	9	39	93	274	42	92	140	275	60	76	139	218	24	87	157
	1	319	50	103	166	47	3	13	31	91	20	29	42	92	18	29	45	89	9	32	48
	2	320	46	95	179	47	3	13	31	92	10	29	53	92	25	23	44	89	8	30	51
	3	319	39	96	184	47	3	13	31	91	12	34	45	91	17	24	50	90	7	25	58
5	All	1096	215	322	559	273	52	83	138	278	69	78	131	276	70	71	135	269	24	90	155
	1	367	71	112	184	91	17	25	49	95	23	29	43	92	22	24	46	89	9	34	46
	2	364	70	109	185	91	18	31	42	91	21	23	47	92	23	25	44	90	8	30	52
	3	365	74	101	190	91	17	27	47	92	25	26	41	92	25	22	45	90	7	26	57
6	All	931	170	246	515	112	17	21	74	276	79	74	123	275	55	70	150	268	19	81	168
	1	309	50	82	177	37	33	8	26	92	25	23	44	92	17	22	53	88	5	29	54
	2	310	67	89	154	37	9	8	20	92	28	26	38	91	21	27	43	90	9	28	53
	3	312	53	75	184	38	5	5	28	92	26	25	41	92	17	21	54	90	5	24	61

*Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

**Wind code

R - Wind blowing from Rubbertown towards the station

NR - Wind blowing from directions other than Rubbertown

M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-18 - Part A. CALCIUM IN SUSPENDED PARTICULATE MATTER; BY STATION, SAMPLING PERIOD, SEASON, AND WIND DIRECTION

Number of samples represented is given in part B of this table.

Sampling station	Sampling period*	Wind ratio** $\frac{R}{NR}$ (Sept. '56 -May. '57)	Calcium particulate concentration (geometric mean conc. in micrograms per cubic meter of air)															
			Total Sep '56-May '57				Sept, Oct, Nov '56				Dec '56 Jan Feb '57				Mar, Apr, May '57			
			Wind**				Wind				Wind				Wind			
			All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5, &6)	All	2.68	3.5	5.9	2.2	4.9	5.5	7.2	5.0	5.3	2.6	4.6	1.7	3.4	2.8	6.9	1.6	4.9
	1	2.79	2.8	5.3	1.9	3.4	5.7	7.6	5.9	3.8	1.8	4.4	1.2	1.3°	2.6	5.9	1.7	3.9
	22	2.75	3.2	5.5	2.0	4.8	4.6	6.0	3.8	5.0	2.5	4.3	1.7	4.0	2.4	6.7	1.4	5.0
	3	2.44	4.6	6.6	2.7	6.3	6.9	7.9	5.9	7.4	3.8	5.7	2.3	5.4	3.3	8.6	1.6	5.7
1	All	3.20	3.4	6.4	2.0	6.6	5.4	7.8	4.8	6.1	2.5	5.1	1.6	4.9	2.7	6.2	1.6	6.3
	1	3.38	2.8	5.4	1.6	5.1	5.0	12.8	3.2	5.4	1.8	4.6	1.1	4.2	3.3	8.0	1.4	4.9
		3.32	3.3	7.3	2.2	5.1	5.2	7.3	4.3	5.4	2.6	6.8	1.8	2.8	2.2	8.4	1.5	6.5
		1.96	4.3	5.1	2.6	7.2	5.4	5.7	4.5	7.8	3.6	4.3	2.4	6.0	3.5	5.5	1.8	7.6
2	All	0.88	3.8	2.9	3.3	5.3	5.2	4.6	4.4	6.5	2.8	2.4	2.3	5.1	3.2	2.7	3.3	3.5
	1	1.04	2.7	2.5	2.4	3.7	4.0	3.5	3.1	5.1	2.1	2.2	1.7	4.8	2.2	2.2	2.7	1.1
	2	0.67	3.9	2.6	3.9	4.8	4.8	5.3	4.6	4.9	3.2	1.9	3.3	6.5	3.5	2.3	3.8	3.6
	3	1.38	5.1	4.7	3.4	7.0	7.3	6.5	5.5	9.1	3.5	7.1	2.3	5.0	4.3	3.0	3.5	6.0
3	All	3.37	3.7	6.4	1.9	3.8	4.8	8.9	4.6	4.1	2.7	6.0	1.8	4.3	1.5	1.8	1.1	2.7
	1	2.35	4.3	8.0	3.4	4.7	6.8	10.9	6.9	5.3	4.5	8.7	3.9	4.2	2.1	1.7	1.9	3.8
	2	3.50	2.2	4.9	1.4	4.4	4.2	6.7	2.9	5.0	2.4	5.3	1.5	8.9	1.0	0.3	0.9	1.8
	3	4.38	2.4	7.0	1.6	3.1	3.9	9.8	5.1	2.9	2.1	5.2	1.2	3.9	1.6	11.5	0.9	2.9
4	All	2.63	3.[illegible]	5.0	1.9	4.1	4.4	5.6	3.8	4.5	2.3	3.8	1.5	3.6	2.4	6.3	1.3	3.8
	1	2.71	2.2	3.8	1.4	2.7	3.8	4.9	2.2	3.3	1.6	3.5	1.0	1.3	2.2	3.6	1.6	4.0
	2	2.05	2.8	3.9	1.9	4.5	4.0	4.5	3.3	4.5	2.2	2.1	1.8	7.6	2.2	7.8	1.1	3.4
	3	3.36	5.1	8.4	2.5	4.8	6.6	8.0	7.5	5.5	3.8	8.2	1.9	5.1	2.8	9.3	1.3	3.9
5	All	2.92	4.1	7.3	2.5	4.9	6.1	9.2	4.1	5.9	2.8	5.8	1.5	4.2	2.8	7.8	1.4	4.3
	1	4.00	2.9	6.8	1.7	3.6	4.8	9.9	3.4	4.1	2.1	4.8	1.1	3.2	2.6	8.3	1.6	3.3
	2	3.78	3.4	6.8	1.8	4.9	5.1	7.4	3.8	5.2	2.7	6.1	1.5	4.1	2.5	6.9	1.3	4.4
	3	3.19	4.9	8.3°	2.6	6.3	8.2	10.5	6.2	8.7	4.0	6.5	2.3	4.9	3.3	9.3	1.3	5.5
6	All	1.88	3.6	4.9	2.6	4.9	4.7	5.8	5.0	4.9	2.9	3.8	2.3	3.9	2.3	6.2	2.2	5.7
	1	1.65	2.9	4.3	2.6	2.9	3.3	5.3	3.1	2.8	2.4	3.2	2.1	2.3	3.2	6.0	2.6	3.7
	2	2.09	3.3	4.7	2.3	4.9	5.6	5.3	3.6	5.0	2.6	4.1	2.0	1.9	2.7	5.1	1.6	8.1
	3	1.76	5.0	5.8	3.3	6.9	7.0	7.0	5.8	7.9	3.8	4.1	2.8	5.8	4.3	11.3	2.3	6.7

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown toward the station
NR - Wind blowing from directions other than Rubbertown

M - Mixed winds, partly from Rubbertown, partly from other directions

Table 3-18 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SAMPLERS AND ANALYZED FOR CALCIUM; BY STATION, SAMPLING PERIOD, SEASON AND WIND DIRECTION

Values obtained are given in part A of this table.

Sampling station	Sampling period*	Number of samples															
		Total Sep '56-May '57				Sept, Oct, Nov '56				Dec, '56-Jan, Feb '57				Mar, Apr, May '57			
		Wind**				Wind				Wind				Wind			
		All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5 & 6)	All	1652	385	789	478	603	134	229	240	553	164	288	101	496	87	272	137
	1	552	122	283	147	183	39	74	70	197	58	111	28	172	25	98	49
	2	535	141	274	120	213	48	83	82	171	54	98	19	151	39	93	19
	3	565	122	232	211	207	47	72	88	185	52	79	54	173	23	81	69
1	All	414	77	219	118	155	29	62	64	131	32	77	22	128	16	80	32
	1	147	28	82	37	48	8	21	19	41	14	32	5	48	6	29	13
	2	129	24	75	30	54	10	22	22	39	9	25	5	36	5	28	3
	3	138	25	62	51	53	11	19	23	41	9	20	12	44	5	23	16
2	All	341	42	184	115	142	12	62	68	95	15	58	22	104	15	64	25
	1	114	19	61	34	45	6	17	22	35	8	22	5	34	5	22	7
	2	111	14	71	26	46	3	24	19	28	5	20	33	37	6	27	4
	3	116	9	52	55	51	3	21	27	32	2	16	14	33	4	15	14
3	All	331	39	182	110	127	19	48	60	93	16	55	22	111	4	79	28
	1	99	15	52	32	42	9	15	18	27	4	15	8	30	2	22	6
	2	109	15	69	25	43	7	17	19	27	7	18	2	39	1	34	4
	3	123	9	61	53	42	3	16	23	39	5	22	12	42	1	23	18
4	All	406	99	188	119	152	34	55	63	135	41	68	26	119	24	65	30
	1	130	33	65	32	42	9	16	17	51	16	27	8	37	8	22	7
	2	136	36	65	35	59	14	21	24	39	13	22	4	38	9	22	7
	3	140	30	58	52	51	11	18	22	45	12	19	14	44	7	21	16
5	All	440	116	197	127	153	41	56	56	153	49	75	29	134	26	66	42
	1	145	34	70	41	46	12	19	15	52	16	28	8	47	6	23	18
	2	142	42	69	31	53	14	19	20	48	15	26	7	41	13	24	4
	3	153	40	58	55	54	15	18	21	53	18	21	14	46	7	19	20
6	All	392	93	185	114	143	30	56	57	134	42	68	24	115	21	61	33
	1	130	27	66	37	47	10	18	19	43	12	24	7	40	5	24	11
	2	128	39	65	24	47	10	21	16	45	17	25	3	36	12	19	5
	3	134	27	54	53	49	10	17	22	46	13	19	14	39	4	18	17

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown towards the station

NR - Wind blowing from directions other than Rubbertown

M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-19 - Part A. CHLORIDES IN SUSPENDED PARTICULATE MATTER; BY STATION, SAMPLING PERIOD, SEASON, AND WIND DIRECTION

Number of samples represented is given in part B of this table.

Sampling station	Sampling period*	Wind ratio** R/NR (Sep '56-May '57)	Chloride particulate concentration (geometric mean conc. in micrograms per cubic meter of air)															
			Total Sep '56-May '57				Sept, Oct, Nov '56				Dec '56 Jan, Feb '57				Mar, Apr, May '57			
			Wind**					Wind			Wind				Wind			
			All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5, & 6)	All	2.47	2.1	3.7	1.5	2.5	2.5	3.6	1.7	2.7	2.2	4.5	1.4	2.8	1.8	2.8	1.4	2.0
	1	2.67	2.2	4.3	1.5	2.6	2.8	3.7	1.1	3.1	2.4	5.2	1.5	3.3	1.8	3.2	1.5	2.0
	2	2.29	1.9	3.2	1.4	2.1	2.0	3.1	1.4	2.2	2.0	4.0	1.4	2.2	1.6	2.3	1.3	1.6
	3	2.47	2.3	3.7	1.5	2.7	2.9	4.0	2.0	3.0	2.5	4.3	1.6	2.8	2.0	3.3	1.4	2.1
1	All	2.12	2.1	3.4	1.6	2.8	2.3	3.4	1.5	2.8	2.2	4.0	1.6	3.1	1.9	2.7	1.5	2.8
	1	2.24	2.3	3.8	1.7	3.1	2.7	3.6	1.6	3.7	2.4	4.6	1.6	3.6	2.0	2.5	1.7	2.5
	2	2.43	1.8	3.4	1.4	2.0	1.9	3.3	1.2	2.1	2.0	4.4	1.5	2.3	1.5	2.1	1.4	1.3
	3	1.94	2.3	3.1	1.6	3.2	2.5	3.2	1.9	2.6	2.3	2.9	1.7	3.4	2.2	3.1	1.5	3.5
2	All	.94	1.9	1.6	1.7	2.5	2.2	1.7	1.9	3.0	3.1	1.8	1.9	2.8	1.6	1.6	1.5	1.9
	1	.88	1.8	1.5	1.7	2.4	2.0	1.2	1.8	3.0	1.9	1.8	1.8	2.8	1.5	1.5	1.6	1.5
	2	.94	1.6	1.5	1.6	1.7	1.8	1.9	1.7	1.9	1.9	1.6	2.0	2.4	1.4	1.3	1.4	1.5
	3	1.47	2.4	2.8	1.9	3.1	3.0	4.1	2.2	7.2	2.5	2.4	2.2	3.0	1.9	2.4	1.6	2.3
3	All	2.73	1.5	3.0	1.1	1.9	1.4	2.4	1.0	1.7	1.6	4.1	1.1	2.0	1.3	2.4	1.1	2.3
	1	2.36	1.4	2.6	1.1	1.7	1.2	1.6	1.1	1.2	1.7	5.5	1.2	1.9	1.5	4.7	1.1	3.1
	2	3.70	1.6	3.7	1.0	2.2	1.6	4.2	0.8	2.4	1.6	4.1	1.0	3.3	1.2	1.6	1.1	1.6
	3	2.36	1.4	2.6	1.1	1.9	1.4	2.7	1.0	2.0	1.4	3.2	1.0	1.8	1.4	1.4	1.1	2.0
4	All	4.00	2.0	4.8	1.2	2.2	2.6	4.7	1.5	2.7	2.0	5.5	1.0	2.2	1.6	3.9	1.2	1.8
	1	4.92	2.2	5.9	1.2	2.6	3.7	8.4	1.8	3.5	2.8	6.0	1.1	2.1	1.5	3.6	1.2	1.7
	2	3.55	1.8	3.9	1.1	2.2	2.0	3.3	1.2	2.0	1.8	4.8	1.0	2.2	1.6	3.5	1.1	2.4
	3	3.92	2.0	4.7	1.2	2.0	2.5	3.8	1.5	2.9	2.0	2.1	1.1	2.1	1.7	4.6	1.3	1.6
5	All	2.64	2.2	3.7	1.4	2.4	2.4	3.6	1.7	2.4	2.5	4.8	1.5	3.0	1.6	2.4	1.3	2.0
	1	2.80	2.1	4.2	1.5	2.2	2.1	2.4	1.7	2.4	2.6	6.1	1.3	3.6	1.6	4.2	1.4	1.7
	2	2.14	1.9	3.0	1.4	2.1	2.3	3.7	1.5	2.3	2.1	3.8	1.5	2.0	1.5	1.9	1.3	1.5
	3	2.87	2.5	4.3	1.5	2.7	3.0	4.7	2.1	2.6	2.8	4.8	1.6	3.1	1.9	2.7	1.5	2.1
6	All	1.61	2.3	2.9	1.8	2.7	2.8	2.7	2.1	3.1	2.4	3.3	1.9	3.1	2.0	2.2	1.7	2.5
	1	1.67	2.4	3.0	1.8	2.7	3.1	1.7	1.9	3.0	2.6	3.9	1.8	3.7	1.9	2.6	1.7	2.1
	2	2.12	2.0	3.6	1.7	2.0	1.9	1.9	1.8	2.1	2.2	3.4	1.6	2.1	1.9	2.1	1.8	1.9
	3	1.55	2.6	3.1	2.0	3.0	3.5	4.5	2.6	4.0	2.4	2.7	1.9	3.2	2.1	2.4	1.8	2.5

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown toward the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-19 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SAMPLERS AND ANALYZED FOR CHLORIDES; BY STATION, SAMPLING PERIOD, SEASON, AND WIND DIRECTION

Values obtained are given in part A of this table.

Sampling	Sampling period *	Number of samples															
		Total Sep '56-May '57				Sep, Oct, Nov '56				Dec '56-Jan, Feb '57				Mar, Apr, May '57			
		Wind**				Wind				Wind				Wind			
		All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville	All	1423	360	712	351	372	114	140	118	552	163	290	99	499	83	282	134
	1	484	111	258	115	114	334	43	37	196	57	111	88	499	83	282	134
	2	455	130	247	78	133	38	54	51	172	54	99	19	150	38	94	18
	3	484	119	207	158	125	42	43	40	184	52	80	52	175	25	84	66
1	All	365	81	199	85	101	30	40	31	133	32	79	22	131	19	80	32
	1	133	29	75	29	33	9	13	11	51	14	32	5	49	6	30	13
	2	112	26	68	18	35	10	16	9	40	9	25	6	37	7	27	3
	3	120	26	56	38	33	11	11	11	42	9	22	11	45	6	23	16
2	All	295	38	176	81	88	11	43	34	95	14	59	22	112	13	74	25
	1	101	18	57	26	29	6	11	12	37	8	23	6	35	4	23	8
	2	100	13	69	18	28	3	15	10	30	5	21	4	42	5	33	4
	3	94	7	50	37	31	2	17	12	28	1	15	12	35	4	18	13
3	All	301	41	182	78	89	18	42	29	91	16	54	21	121	7	86	28
	1	94	16	53	25	32	9	12	11	28	4	16	8	34	3	25	6
	2	98	16	69	13	29	7	15	7	27	7	18	2	42	2	36	4
	3	109	9	60	40	28	2	15	11	36	5	20	11	45	2	25	18
4	All	349	94	170	85	89	30	30	29	137	41	69	27	123	23	71	29
	1	121	33	63	25	31	10	11	10	52	16	28	8	38	7	24	7
	2	110	32	56	22	33	11	10	12	39	13	22	4	38	8	24	6
	3	118	29	51	38	25	9	9	7	46	12	19	15	47	8	23	16
5	All	388	105	182	101	102	34	36	32	150	48	74	28	136	23	72	41
	1	127	29	65	33	27	10	11	6	51	15	28	8	49	4	26	19
	2	128	38	66	24	39	11	14	14	47	15	26	6	42	12	26	4
	3	133	38	51	44	36	13	11	12	52	18	20	14	45	7	20	18
6	All	321	80	161	80	80	20	34	26	132	42	68	22	109	18	59	32
	1	103	20	55	28	23	5	8	10	42	12	23	7	38	3	24	11
	2	105	34	57	14	26	6	14	6	46	17	26	3	33	11	17	5
	3	113	26	49	38	31	9	12	10	44	13	19	12	38	4	18	16

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown towards the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-20 - Part A. ORGANICS IN SUSPENDED PARTICULATE MATTER: BY STATION, SAMPLING PERIOD, AND MONTH - 1956

Number of samples represented is given in part B of this table.

Sampling station	Sampling period*	Season ratio Nov. conc./July conc.	Organic particulate concentration (geometric mean conc. in micrograms per cubic meter of air)											
			Jan-Nov mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Total for Western Louisville (1, 4, 5, & 6)	All	3.3	6.5	19.4	18.1	17.1	12.9	6.7	3.5	2.9	4.2	6.6	12.4	9.7
	1	3.1	6.0	19.3	19.5	17.6	12.9	6.5	3.3	2.7	4.1	5.8	10.6	8.5
	2	3.9	4.6	19.3	15.1	12.4	9.2	5.1	2.1	1.9	3.1	4.9	8.7	7.4
	3	2.9	9.8	19.9	20.2	23.0	18.2	8.9	6.2	4.9	5.9	10.0	20.6	14.1
1	All	3.9	7.8	19.4	18.1	16.4	13.0	6.4	3.0	2.7	4.2	6.2	11.8	10.4
	1	3.3	7.7	19.3	19.5	17.3	13.0	6.6	2.4	2.8	4.5	5.6	10.6	9.1
	2	4.9	5.8	19.3	15.1	12.1	9.8	4.5	2.1	1.6	3.1	4.2	8.5	7.8
	3	3.5	10.9	19.9	20.2	20.9	17.4	8.8	5.2	4.2	5.6	10.1	18.6	14.7
2	All	2.4	8.9		16.7	14.9	12.6	8.0	4.6	5.0	6.1	8.8	15.0	12.0
	1	1.7	9.1		14.3	15.9	13.3	8.1	5.4	5.5	6.5	8.7	14.3	9.4
	2	2.7	5.6		13.8	10.2	8.4	5.6	2.1	3.1	3.5	5.3	8.6	8.4
	3	2.6	13.8		22.7	20.3	17.6	11.5	8.5	7.1	9.8	14.6	25.4	18.4
3	All	3.2	3.9				8.0	4.7	1.7	1.8	3.3	5.6	6.9	5.7
	1	4.3	4.3				8.0	4.7	1.8	1.8	4.2	6.4	8.4	7.7
	2	2.4	3.5				6.3	3.6	1.4	1.8	2.9	5.3	6.5	4.4
	3	3.0	4.1				9.9	6.2	1.8	1.9	2.9	5.0	6.0	5.8
4	All	3.0	3.9					4.3	2.6	2.3	2.9	4.9	9.3	6.9
	1	3.3	3.6					4.0	2.6	1.9	3.0	4.3	8.3	6.2
	2	2.9	3.4					4.1	1.8	2.0	2.6	4.4	7.7	5.9
	3	2.9	5.0					4.9	3.7	3.0	3.0	6.0	12.8	8.7
5	All	3.3	7.1			20.6	12.8	8.4	4.3	3.1	4.2	7.4	15.2	10.2
	1	2.8	6.6			19.4	12.8	8.0	3.9	3.0	4.4	6.5	12.8	8.5
	2	4.4	4.6			13.3	8.7	5.8	2.5	1.7	2.6	5.3	10.2	7.5
	3	2.7	11.9			31.6	19.1	12.5	8.5	6.1	6.4	11.7	25.9	16.2
6	All	3.8	6.9					8.3	4.5	3.9	6.2	8.3	14.1	14.7
	1	4.0	5.9					7.0	4.5	3.2	5.1	6.9	11.0	12.7
	2	4.0	4.5					8.6	2.3	2.5	4.3	5.7	8.9	10.1
	3	3.2	12.6					9.5	9.1	7.4	10.8	14.4	28.6	23.8

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

Table 3-20 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SIMPLERS AND ANALYZED FOR BENZENE SOLUBLE ORGANICS; BY STATION, SAMPLING PERIOD, AND MONTH; 1956

Values obtained are given in Part A of this table.

Sampling station	Sampling period*	Number of Samples											
		Jan-Nov 1956	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Total for Western Louisville (1, 4, 5, & 6)	All	2650	57	84	116	180	259	359	371	368	355	312	189
	1	874	20	28	37	60	86	120	124	122	118	99	60
	2	887	21	28	39	60	86	119	123	123	119	107	62
	3	889	16	28	40	60	87	120	124	123	118	106	67
1	All	903	57	84	93	90	93	89	93	91	86	79	48
	1	300	20	28	31	30	31	30	31	29	29	26	15
	2	303	21	28	31	30	31	29	31	31	29	27	15
	3	300	16	28	31	30	31	30	31	31	28	26	18
2	All	810		44	94	90	93	90	93	92	89	79	46
	1	263		13	31	30	31	30	31	30	30	24	13
	2	268		15	31	30	31	30	31	31	29	26	14
	3	279		16	32	30	31	30	31	31	30	29	19
3	All	646				90	93	90	93	89	73	83	35
	1	212				30	31	30	31	30	24	26	10
	2	216				30	31	30	31	28	24	30	12
	3	218				30	31	30	31	31	25	27	13
4	All	546					51	90	93	92	89	76	55
	1	179					17	30	31	31	29	23	18
	2	184					17	30	31	31	30	27	18
	3	183					17	30	31	30	30	26	19
5	All	701			23	90	93	90	93	92	90	76	54
	1	229			6	30	31	30	31	31	30	24	16
	2	234			8	30	31	30	31	30	30	25	19
	3	238			9	30	31	30	31	31	30	27	19
6	All	500					22	90	92	93	90	81	32
	1	166					7	30	31	31	30	26	11
	2	166					7	30	30	31	30	28	10
	3	168					8	30	31	31	30	27	11

* Sampling periods: 1-2400 to 0800; 2-0800 to 1600; 3-1600 to 2400

Table 3-21 - Part A. ORGANICS IN SUSPENDED PARTICULATE MATTER:
BY STATION, SAMPLING PERIOD, SEASON, AND WIND DIRECTION - 1956

Number of samples represented is given in Part B of this table.

Sampling station	Sampling period*	Wind ratio ** R conc. / N R conc. (Jan - Nov)	Organic particulate concentration (geometric mean conc. in micrograms per cubic meter of air) Total Jan - Nov Wind**				Jan Feb Mar Wind				Apr May Jun Wind				Jul Aug Sep Wind				Oct Nov Wind			
			All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5, &6)	All	0.85	6.5	6.2	7.3	6.1	17.9	17.2	17.7	18.5	5.8	7.1	6.0	5.4	4.3	4.0	4.9	4.1	11.3	9.0	10.9	13.7
	1	0.78	6.0	5.2	6.7	5.9	18.6	20.6	17.8	18.7	5.5	7.1	5.4	5.3	4.0	3.2	4.7	4.0	9.7	8.6	9.4	19.6
	2	0.94	4.6	5.0	6.3	4.1	14.6	14.7	14.9	14.4	3.9	5.5	4.0	3.5	3.0	2.9	3.3	2.9	8.2	7.2	8.2	9.4
	3	0.83	9.8	9.1	19.9	9.3	21.4	17.7	20.4	24.0	8.9	9.6	10.8	8.0	6.6	6.9	6.9	6.2	17 8	12.1	18.0	21.7
1	All	0.92	7.8	8.0	8.7	7.2	17.7	17.1	17.2	18.4	6.3	7.5	6.5	5.9	4.1	3.8	5.0	3.7	11.2	9.4	10.0	14.4
	1	0.86	7.7	7.1	8.3	7.5	18.6	20.6	17.2	19.1	5.9	7.5	5.6	5.8	4.1	3.1	5.3	3.9	10.0	7.5	9.1	12.9
	2	1.08	5.8	7.1	6.6	4.9	14.8	14.7	15.1	14.5	4.5	5.5	4.6	4.3	2.7	2.9	3.3	2.4	8.2	8.5	6.9	10.5
	3	0.84	10.9	19.3	12.2	10.1	20.4	17.1	19.5	23.0	9.2	10.3	11.4	8.0	6.1	6.1	6.3	5.9	16.9	12.1	17.0	20.4
2	All	0.74	8.9	6.3	8.5	9.6	15.4	12.2	13.7	17.2	7.8	5.1	7.5	8.3	6.4	3.4	6.3	6.6	13.8	5.9	11.5	20.7
	1	0.65	9.1	5.3	8.2	10.4	15.4	9.3	16.4	15.6	8.4	4.8	7.4	9.9	6.8	3.4	6.0	7.4	12.4	4.9	10.4	20.6
	2	0.93	5.6	5.4	5.8	5.4	11.2	11.9	9.8	12.0	4.6	3.9	4.8	4.7	3.8	3.0	4.1	3.8	8.6	5.8	9.0	8.9
	3	0.78	13.8	9.9	12.7	15.0	21.1	15.4	15.8	26.0	12.0	13.4	12.3	11.7	10.0	4.2	10.0	10.3	22.3	7.9	16.4	34.3
3	All	1.75	3.9	5.6	3.2	4.4					4.0	5.6	3.7	4.1	3.1	3.0	2.4	3.9	6.5	9.7	4.5	8.0
	1	1.79	4.3	5.9	3.3	4.8					4.1	7.2	3.5	4.3	3.4	2.3	2.7	4.4	8.2	11.9	5.4	9.4
	2	1.86	3.5	5.4	2.9	3.9					3.2	4.8	3.0	3.2	2.9	3.6	2.4	3.5	5.8	8.7	3.7	8.3
	3	1.57	4.1	5.5	3.5	4.5					4.8	4.7	4.8	4.8	2.9	3.6	2.3	3.6	5.9	7.9	4.7	6.7
4	All	0.88	3.9	3.8	4.3	3.8					3.1	2.1	3.2	3.2	3.1	2.7	3.6	3.0	8.2	7.0	7.9	9.4
	1	0.86	3.6	3.0	3.5	3.9					3.1	2.3	2.2	3.6	2.9	2.4	3.2	2.9	7.3	6.5	6.6	8.2
	2	1.17	3.4	4.2	3.6	3.0					2.4	1.4	2.3	2.6	2.8	3.1	3.0	2.7	6.9	6.7	7.0	7.0
	3	0.72	5.0	4.4	6.1	4.5					4.1	2.9	6.4	3.5	3.8	3.0	4.7	3.4	10.9	7.9	10.4	13.4
5	All	0.85	7.1	6.8	8.0	6.8	20.6	17.8	23.9	19.3	7.8	8.7	8.0	7.3	4.6	4.4	5.5	4.2	12.9	19.1	12.2	16.9
	1	0.84	6.6	6.3	7.5	6.1	19.4		25.8	14.6	7.4	9.0	7.5	6.8	4.4	3.9	5.4	4.1	10.8	10.5	10.2	11.8
	2	0.89	4.6	4.7	5.3	4.1	13.3	14.8	12.4	13.1	5.0	6.6	5.2	4.3	2.8	2.5	3.2	2.8	8.9	7.0	9.2	10.9
	3	0.77	11.9	10.2	13.3	12.1	31.6	26.0	34.3	31.2	12.7	11.4	13.6	12.7	7.6	7.7	9.1	6.8	21.4	14.0	20.8	29.7
6	All	0.72	6.9	5.6	7.8	7.1					5.1	6.5	4.6	5.0	5.8	4.7	6.0	6.6	14.2	9.9	14.8	16.5
	1	0.55	5.9	4.2	7.6	5.9					4.9	4.3	7.0	4.5	4.8	3.3	5.5	5.5	11.5	9.7	12.9	11.1
	2	0.84	4.5	4.2	5.0	4.3					2.9	6.0	1.9	2.5	3.9	3.2	3.9	4.6	9.2	6.7	9.9	10.8
	3	0.77	12.6	10.7	13.9	12.8					9.1	9.7	9.2	9.0	10.4	9.7	9.8	11.3	27.1	17.9	31.9	27.8

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code
R - Wind blowing from Rubbertown towards the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-21 (continued)

Part B. NUMBER OF PARTICULATE SAMPLES COLLECTED WITH HIGH VOLUME SAMPLERS AND ANALYZED FOR BENZENE SOLUBLE ORGANICS; BY STATION, SAMPLING PERIOD, SEASON AND WIND DIRECTION, 1956

Values obtained are given in part A of this table.

Sampling station	Sampling period*	Number of Samples																			
		Total Jan - Nov				Jan, Feb Mar				Apr, May, Jun				Jul, Aug, Sep				Oct, Nov			
		Wind**				Wind				Wind				Wind				Wind			
		All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M	All	R	NR	M
Total for Western Louisville 1, 4, 5, & 6	All	2650	499	871	1280	257	39	108	110	798	114	237	447	1094	230	325	539	501	116	201	184
	1	874	163	283	428	85	12	34	39	226	35	77	154	364	85	107	172	159	31	65	63
	2	887	173	297	417	88	16	35	37	265	42	86	137	365	69	191	195	169	46	75	48
	3	889	163	291	435	84	11	39	34	267	37	74	156	365	76	117	172	173	39	61	73
1	All	903	139	334	430	234	36	100	98	272	36	94	142	270	40	85	145	127	27	55	45
	1	300	48	110	142	79	12	31	36	91	12	31	48	89	17	29	43	41	7	19	15
	2	303	46	110	147	80	14	33	33	90	12	34	44	91	10	24	57	42	10	19	13
	3	300	45	114	141	75	10	36	29	91	12	29	50	90	13	32	45	44	110	17	17
2	All	810	52	301	457	138	13	47	78	273	18	99	156	274	7	98	169	125	14	57	54
	1	263	16	103	144	44	3	16	25	91	6	37	48	91	1	35	55	37	6	15	16
	2	268	23	99	146	46	6	15	25	91	9	32	50	91	4	30	57	40	4	22	14
	3	279	13	99	167	48	4	16	28	91	3	30	58	92	2	33	57	48	4	20	24
3	All	646	48	274	324					273	13	110	150	255	15	117	123	118	20	47	51
	1	212	18	77	117					91	5	31	55	85	5	34	46	36	8	12	16
	2	216	20	104	92					91	4	43	44	83	8	42	33	42	8	19	15
	3	218	10	93	115					91	4	36	51	87	2	41	44	40	4	16	20
4	All	546	82	179	285					141	9	39	93	274	42	92	140	131	31	48	52
	1	179	30	57	92					47	3	13	31	91	20	29	42	41	7	15	19
	2	184	27	59	98					47	3	13	31	92	10	29	53	45	14	17	14
	3	183	25	63	95					47	3	13	31	91	12	34	45	45	10	16	19
5	All	701	160	216	325	23	3	8	12	273	52	83	138	275	69	75	131	130	36	50	44
	1	229	50	70	109	6		3	3	91	17	25	49	92	23	26	43	40	10	16	14
	2	234	54	75	105	8	2	2	4	91	18	31	42	91	21	23	47	44	13	19	12
	3	238	56	71	111	9	1	3	5	91	17	27	47	92	25	26	41	46	13	15	18
6	All	500	118	142	240					112	17	21	74	275	79	73	123	113	22	48	43
	1	166	35	46	85					37	3	8	26	92	25	23	44	37	7	15	15
	2	166	46	53	67					37	9	8	20	91	28	25	38	38	9	20	9
	3	168	37	43	88					38	5	5	28	92	26	25	41	38	6	13	19

* Sampling periods: 1-2400 to 0800; 210800 to 1600; 31-600 to 2400

** Wind Code

R - Wind blowing from Rubbertown towards the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-22. SULFATES IN SUSPENDED PARTICULATE MATTER; BY STATION, SAMPLING PERIOD AND WIND DIRECTION - SEPT. - NOV., 1956

Sampling station	Sampling period*	Wind ratio** $\frac{R}{NR}$	Sulfate particulate concentration (geometric mean conc. in micrograms per cubic meter of air)							
			Concentration				No. of samples			
			Wind**				Wind			
			All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5, & 6)	All	0.91	10.1	9.2	10.2	11.0	298	98	100	100
	1	1.09	9.3	10.0	9.2	8.7	90	31	28	31
	2	0.93	10.3	9.4	10.1	11.7	114	35	47	32
	3	0.72	10.6	8.2	11.4	12.6	94	32	25	37
1	All	1.02	10.7	10.1	9.9	12.4	79	27	26	26
	1	1.67	10.5	13.0	7.8	10.2	24	9	6	9
	2	0.90	10.4	8.9	9.9	14.3	30	9	14	7
	3	0.72	11.4	9.0	12.5	13.3	25	9	6	10
2	All	1.27	8.6	9.0	7.1	9.9	59	5	24	30
	1	1.26	8.8	7.8	6.2	10.3	16	2	4	10
	2	1.22	7.5	6.7	5.5	10.0	19	2	8	9
	3	2.36	9.4	21.0	8.9	9.4	24	1	12	11
3	All	2.54	9.2	17.5	6.9	9.2	75	14	33	28
	1	1.92	11.1	17.7	9.2	10.2	26	6	10	10
	2	2.35	11.3	16.7	7.1	16.9	24	7	11	6
	3	4.21	6.1	22.3	5.3	6.3	25	1	12	12
4	All	0.91	9.8	9.0	9.9	10.5	73	26	21	26
	1	0.69	9.8	8.6	12.4	8.9	27	9	8	10
	2	1.20	10.1	10.2	8.5	11.8	29	10	9	10
	3	0.90	9.2	8.0	8.9	10.9	17	7	4	6
5	All	1.15	9.9	10.8	9.4	9.6	79	27	26	26
	1	1.68	8.9	11.9	7.1	7.6	20	8	8	4
	2	1.05	10.9	11.7	11.1	10.2	32	10	11	11
	3	0.89	9.7	9.1	10.2	9.9	27	9	7	11
6	All	0.56	9.9	6.4	11.5	11.9	67	18	27	22
	1	0.58	7.8	6.0	10.3	7.4	19	5	6	8
	2	0.56	9.6	6.2	11.0	12.1	23	6	13	4
	3	0.51	12.4	6.7	13.2	17.2	25	7	8	10

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown towards the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-23. NITRATES IN SUSPENDED PARTICULATE MATTER; BY STATION, SAMPLING PERIOD, AND WIND DIRECTION - SEPT. - NOV., 1956

Sampling station	Sampling periods*	Wind ratio** $\frac{R}{NR}$	Nitrate particulate concentration (geometric mean conc. in micrograms per cubic meter of air)							
			Concentration Wind**				No. of samples Wind			
			All	R	NR	M	All	R	NR	M
Total for Western Louisville (1, 4, 5, & 6)	All	0.59	1.47	1.07	1.82	1.61	282	91	93	98
	1	0.50	1.16	0.81	1.63	1.21	86	29	27	30
	2	0.68	1.74	1.32	1.95	2.00	107	33	42	32
	3	0.61	1.51	1.12	1.82	1.70	89	29	24	36
1	All	0.78	1.45	1.18	1.52	1.72	78	28	24	26
	1	1.08	1.01	0.80	0.74	1.58	24	9	6	9
	2	1.12	1.78	1.73	1.54	2.44	30	10	13	7
	3	0.33	1.59	1.14	3.48	1.46	24	9	5	10
2	All	0.27	1.62	0.48	1.74	1.74	57	3	24	30
	1	0.30	1.51	0.40	1.35	1.81	15	1	4	10
	2	0.12	1.57	0.20	1.64	1.89	18	1	8	9
	3	0.71	1.75	1.40	1.97	1.56	24	1	12	11
3	All	2.56	1.46	2.87	1.12	1.41	73	14	31	28
	1	1.33	1.53	2.41	1.81	1.02	24	6	8	10
	2	3.41	1.86	3.31	0.97	2.48	24	7	11	6
	3	3.15	1.11	2.90	0.92	1.23	25	1	12	12
4	All	0.43	1.23	0.87	2.03	1.20	67	24	17	26
	1	0.26	1.18	0.69	2.69	1.27	25	8	7	10
	2	0.50	1.44	1.01	2.01	1.83	26	10	6	10
	3	0.68	0.96	0.94	1.38	0.78	16	6	4	6
5	All	0.61	1.62	1.11	1.82	2.05	75	24	25	26
	1	0.61	1.23	1.02	1.68	0.89	19	7	8	4
	2	0.40	1.99	1.15	2.89	2.21	30	9	10	11
	3	1.12	1.57	1.15	1.03	2.56	26	8	7	11
6	All	0.60	1.63	1.19	1.97	1.59	62	15	27	20
	1	0.40	1.27	0.77	1.91	1.28	18	5	6	7
	2	0.97	1.70	1.77	1.82	1.31	21	4	13	4
	3	0.58	1.72	1.31	2.31	2.04	23	6	8	9

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind code

R - Wind blowing from Rubbertown towards the station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

Table 3-24. COMPARISON OF SUSPENDED PARTICULATE MATTER IN WESTERN LOUISVILLE DURING OCTOBER 15-19, 1956. AN ATMOSPHERIC STAGNATION PERIOD WITH CONCENTRATIONS DURING REST OF OCTOBER (Stations 1, 4, 5, 6)

Air-borne particulate measurement	Type of mean		Ratios of concentrations		Mean concentration ($\mu g/m^3$)		
					October 15-19		Rest of Oct.
	Arith-metic	Geo-metric	Oct. 15-19 Rest of Oct. (all sampling periods)	Sampling period 3 All sampling periods (during Oct. 15-19)	All sampling periods	Sampling period 3	(all sampling periods)
Total	x		1.44	1.35	192	260	133
Calcium		x	1.95	1.16	9.0	10.5	4.6
Chloride		x	1.25	0.97	3.0	2.9	2.4
Sulfate		x	1.53	1.03	15.4	15.9	10.1
Organic		x	1.62	1.55	18.3	28.4	11.3

Table 3-25. SUSPENDED PARTICULATE MATTER (SOILING); BY MONTH, SAMPLING PERIOD, AND WIND DIRECTION; STATION 5 - MARCH 1956 - APRIL 1957 (COH PER 1000 LINEAR FEET OF AIR (A); MONTHLY MEAN)

Month	Sampling period*				Wind direction**		
	All	1	2	3	R	NR	M
March '56 - April '57	1.9	2.1	1.6	2.1	1.6	1.9	2.1
March 1956	2.1	2.7	1.4	2.5	1.9	2.7	1.9
April	1.9	2.3	1.4	2.1	1.2	2.1	2.1
May	1.2	1.4	1.0	1.2	1.0	1.4	1.2
June	1.0	1.2	0.8	1.0	0.8	1.0	1.0
July	0.6	0.8	0.8	0.6	0.8	0.6	0.6
August	-	-	-	-	-	-	-
September	1.2	1.2	1.2	1.0	1.0	1.2	1.0
October	2.1	2.5	2.1	2.1	2.5	2.1	2.3
November	2.5	2.5	1.9	2.9	2.3	2.3	2.7
December	2.5	2.3	2.1	2.7	2.1	2.5	2.5
January 1957	3.3	3.1	2.9	3.7	2.7	2.7	3.9
February	2.7	2.9	2.3	3.1	2.1	2.5	2.9
March	2.1	2.3	1.6	2.7	1.6	2.3	2.1
April	1.0	1.4	0.8	1.2	0.6	1.0	1.2

* Sampling periods: 1 - 2400 to 0800; 2 - 0800 to 1600; 3 - 1600 to 2400

** Wind direction code:

R - Wind blowing from Rubbertown to sampling station
NR - Wind blowing from directions other than Rubbertown
M - Mixed winds, partly from Rubbertown and partly from other directions

(a) Approx. values. Air sample volumes not precisely measured

Table 3-26. CONCENTRATION OF GASEOUS POLLUTANTS AT STATIONS C AND D; JUNE 18 - AUGUST 16, 1957

Pollutant	Station	Time period sampled (hr. of day)	Concentration (ppb)				Threshold concentration ppb	Ratio
			Median	Mean	Range			Max. conc./Threshold
					Minimum	Maximum		
Aldehydes	C	08-0900	40	170	0	1050	250(a, c)	4.2
		20-2100	50	180	0	740		3.0
	D	08-0900	40	120	0	740		3.0
		20-2100	20	130	0	640		2.6
Hydrogen chloride	C	08-0900	70	260	0	2800	5000(a, c)	0.56
		20-2100	30	70	0	680	5000(b)	0.14
	D	08-0900	30	60	0	270		0.05
		20-2100	60	110	0	950		0.19
Nitrogen oxides, as NO_2	C	08-0900	100	100	0	190	5000(b)	0.04
		20-2100	20	40	0	150		0.03
	D	08-0900	60	70	0	150		0.03
		20-2100	5	20	0	100		0.02
Ozone	C	08-0900	10	10	0	40	100(a, c)	0.4
		20-2100	10	10	0	70	100(b)	0.7
	D	08-0900	10	10	0	20		0.2
		20-2100	10	10	0	30		0.3
Total oxidants	C	08-0900	20	20	0	50	250(a, c)	0.2
		20-2100	10	15	0	25		0.1
	D	08-0900	25	28	0	65		0.26
		20-2100	10	10	0	45		0.18

(a) Eye irritation threshold

(b) Maximum allowable concentration for an industrial working atmosphere recommended by American Conference of Governmental Industrial Hygienists - 1959

(c) Reference 88

Table 3-27. FREQUENCY THAT SULFUR DIOXIDE CONCENTRATION EXCEEDED TASTE OR ODOR THRESHOLD AT STATION B - 1956 (COMPILED FROM HOURLY MAXIMUM VALUES FROM THOMAS AUTOMETER)

Month	Frequency taste threshold exceeded 88/ (300 ppb)		Frequency odor threshold exceeded 88/ (3000 ppb)	
	Percent of days	Percent of hours	Number of days	Number of hours
Total	32	2.6	2	3
Jan	47	5.5	1	1
Feb	47	3.7		
Mar	55	5.1		
Apr	29	1.9		
May	32	1.9		
Jun	22	1.3		
Jul	23	1.8		
Aug	19	1.4	1	2
Sep	23	1.5		
Oct	23	2.2		
Nov	33	2.7		
Dec	29	2.2		

88/ Threshold values from this reference

Table 3-28. GASEOUS POLLUTANT CONCENTRATIONS DETERMINED BY MASS SPECTROMETER IN FREEZE-OUT AND GRAB SAMPLES (CONCENTRATIONS IN PPB BY VOLUME)

Pollutant	Max. conc.	Sample number								
		1	2	3	4	5	6	7	8(d)	9
Approximate total pollutant	68,000	310	740	490	1,040	180	3,300	39,000	68,000	1,500
"Normal traffic gas"	12,870	149	547	305	500		1,980	12,870		360
"Reformed traffic gas"	825	105	73	103	200	95	825			
Gasoline vapor (a)	68,000					56		12,890	68,000	
Parafin hydrocarbons (b)										
Normal butane	3,080								3,080	470
Isobutane	4					4				
Normal pentane	2					2				
Isohexane	2					2				
Normal heptane	60						60			
Olefins (b)										
Cis-2-pentane	2					2				
3-methyl-1-pentene	1					1				
Other aliphatic hydrocarbons										
Acetylene (c)	440	48	80	10	6	6	241	410		440
3-hexyne	1					1				
1, 3 butadiene (b)	1,830					+		1,830		46
Vinyl acetylene	55									55
Benzene homologs (c)										
Benzene	144	4	13	3	12	1	28	144		2
Toluene	270	+	12	3	14	+	8	270		
Xylene and ethyl benzene	121		7	1	4		3	121		
Above C_8H_{10}	2	+		1	2					
C_9H_{12}	1		1							
Above C_9H_{12}	1		1							
Chlorine derivatives										
Methyl chloride	2					2				
Dichloromethane	40				40					
Chloroform	9			9						
Carbon tetrachloride	52	1		52	2	+		8		
Dichloroethane	1					1	1			
Dichloropropane						+				
Vinyl chloride	5,850	+						5,850		70
Dichloroethylene	1	1								
Tetrachlorethylene	8		8			+				
Chloroprene	218				114		4	218		5
Trichloromethane	43						43			
Acrylonitrile	336					+		336		29
Carbon disulfide	6					+				6
Cresol	94				94	+				
Diethyl ether	4						4			
3, 3-dimethyl hexane	31						31			
Ethyl alcohol (c)	168	1	3	2	5	1	17	168		7
Phenol	48				48	+				
1, 1, 3-trimethylcyclohexane	49						49			

(a) In addition to gasoline represented by patterns of normal and reformed traffic gas.

(b) In addition to any of the compounds represented in patterns of normal and reformed traffic gas and average gasoline.

(c) Total of compound in sample.

(d) Because of the high concentration of one substance (a mixture of hydrocarbons resembling gasoline vapors) no attempt was made to further interpret composition.

+ Substance identified but present in concentration below one ppb.

Table 3-29. COMPARISON OF GASEOUS AIR POLLUTANT CONCENTRATIONS IN NON-SELECTIVE SAMPLES WITH ODOR THRESHOLDS

Sample number	Time sampled		Pollutant	Concentration (ppb)		Ratio	Remarks
	Date	Hour CDT		Measured	Median odor Threshold	Measured / Threshold	
4	10-17-56	1139-1222	Phenol Creosol Chloroprene	48 94 114	46 34 27	1 3 4	Stagnant atmospheric condition of several days duration
7	6-28-57	1145-1200	Gasoline Toluene	12,870 265	2,690 103	5 2	
8	12-4-56	0930-0945	Gasoline	68,000	2,690	25	Fumigation during break-up of nocturnal inversion

See figures 3-28 and 3-29 for more detail concerning samples 4 and 7 respectively

Table 3-30. WIND SPEED RATIOS* FOR UPPER AND LOWER QUARTILES OF TOTAL PARTICULATE CONCENTRATIONS AT STATIONS 1, 2, AND 3

Season	Air sampling station	Wind observing station	Quartile	Wind speed (mph)						
				0	1-3	4-7	8-12	13-18	19-24	25+
Winter (Apr., May, Dec., 1956; Jan-March, 1957)	1	1	Upper	280.9	177.9	67.6	71.9	122.5	152.7	
			Lower	14.2	44.3	105.0	134.3	90.7	0.0	
	2	8, 12	Upper	258.6	179.9	111.0	66.1	90.6	113.2	105.3
			Lower	6.7	17.9	64.9	128.4	138.0	114.2	129.6
	3	3	Upper	49.3	128.4	116.9	77.0	74.5	50.2	0.0
			Lower	50.0	63.5	89.6	124.4	114.0	139.5	191.8
Summer (June - Oct., 1956)	1	1	Upper	70.4	108.1	93.2	91.3	131.3	200.0	
			Lower	72.0	90.0	113.6	115.2	55.3	0.0	
	2	8, 12	Upper	154.6	148.3	95.2	63.5	93.9	130.5	
			Lower	55.9	53.3	99.6	132.5	126.0	0.0	
	3	3	Upper	143.5	103.1	82.1	62.5	76.5	387.1	
			Lower	86.6	82.7	100.4	140.7	117.2	0.0	

* The entered values are obtained by multiplying the number of occurrences of a given category of speed and concentration by $100N_t/N_cN_i$, where N_t is the total number of observations during the interval of record, N_c is the number of observations in the given concentration category, and N_i is the number of observations in the given wind speed category.

Table 3-31. INTERCORRELATIONS AMONG METEOROLOGICAL PARAMETERS

Pairs of meteorological parameters	Correlation index	Percent of variance explained
Wind speed on wind direction	0.42	17.6
Temperature on wind direction	0.62	38.4
Stability index on wind direction	0.52	27.0
Temperature on wind speed	0.54	29.2
Stability index on wind speed	0.65	42.3
Stability index on temperature	0.53	28.1

Table 3-32. CORRELATIONS OF OPTICAL DENSITY ON VARIOUS METEOROLOGICAL PARAMETERS

Meteorological parameters	Correlation index	Percent of variance explained
Wind speed	0.69	47.6
Stability index	0.49	24.0
Wind direction	0.36	13.0
Temperature	0.33	10.9

Table 3-33. GRAPHICAL MULTIPLE CURVILINEAR CORRELATIONS

Techniques	Cumulative correlation index	Cumulative percent of variance explained	Percent of variance explained
A. Orders of elimination technique (1st approximations)			
1. Statistical order of elimination			
Wind Speed	0.69	47.6	47.6
Stability index	0.73	53.3	5.7
Wind direction	0.79	62.4	9.1
Temperature	0.80	64.0	1.6
2. Meteorological order of elimination			
Temperature	0.33	10.9	10.9
Wind direction	0.58	33.6	22.7
Wind speed	0.67	44.9	11.3
Stability index	0.69	47.6	2.7
B. Successive approximation technique			
Wind speed	0.73	53.3	53.3
Wind direction	0.78	60.8	7.5
Temperature	0.79	62.4	1.6
Stability index	0.84	70.6	8.2

Table 3-34. STANDARD ERRORS OF ESTIMATE OBTAINED BY VARIOUS METHODS

	S_y	S'_y
A. Orders of elimination technique		
1. Statistical order of elimination		
Wind speed	±.060	±.061
Stability index	±.056	±.062
Wind direction	±.050	±.065
Temperature	±.049	±.056
2. Meteorological order of elimination		
Temperature	±.077	±.072
Wind direction	±.067	±.075
Wind speed	±.061	±.065
Stability index	±.059	±.066
B. Successive approximation technique		
Wind speed	±.056	±.063
Wind direction	±.052	±.068
Temperature	±.051	±.068
Stability index	±.044	±.068

Table 3-35. CHECKS TO DETERMINE REPRESENTATIVENESS OF REGRESSION CURVES USING INDEPENDENT DATA

Techniques	Correlation index	Percent of variance explained
A. Orders of elimination technique		
1. Statistical order of elimination	0.63	39.7
2. Meteorological order of elimination	0.41	16.8
B. Successive approximation technique	0.35	12.3

Table 3-36. COMPOSITION OF SELECTED SUSPENDED PARTICULATE SAMPLES AND METEOROLOGICAL REGIMES AT STATION 1 - APRIL 1956
(CONCENTRATIONS IN MICROGRAMS PER CUBIC METER; RELATIVE CONCENTRATIONS IN PERCENT OF TOTAL)

Sample No.	Meteorological class*	Date	Period	Total concentration	Organic		Mn		Pb		Fe		Cu		Zn		Si	Ti	V	Cr.	Ni	Mo	Co	Bi	Cd	Ba
					Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	Conc.	Conc.	Conc	Conc.	Conc	Conc.	Conc.	Conc.	Conc.
546	Ru	1	2	266	15.2	5.7	.073	.027	.33	.124	2.25	.85	.28	.105	.145	.055	-	.026	.004	-	.0051	-	-	-	-	-
582	Rs	5	1	214	23.5	10.9	-	-	.42	.196	.47	.22	2.48	1.16	-	-	-	-	-	-	-	-	-	-	.0044	-
584	C, As	5	3	229	45	19.6	.062	.027	1.14	.497	1.36	.59	.136	.059	-	-	-	-	-	-	.0035	-	-	.0039	.0039	-
585	A	6	1	122	21.4	17.5	.062	.051	.52	.43	.98	.80	2.09	1.71	.147	.120	-	-	-	-	-	-	-	-	.0090	-
588	Cu	7	1	39	8.0	20.6	.071	.182	.39	1.00	.94	2.41	.32	.82	.37	.95	-	-	-	-	-	-	-	.0037	-	-
590	Cu	7	3	143	10.7	7.5	.066	.046	.36	.25	1.45	1.02	.055	.039	.25	.175	-	-	-	-	.0080	-	-	.0034	-	.025
592	Cu	8	2	35	7.0	20	.028	.080	.30	.86	.33	.94	.313	.373	.187	.533	-	-	-	-	-	-	-	.0037	-	-
593	Cu, A	8	3	58	8.6	14.8	-	-	.194	.335	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
596	A	9	3	146	23.6	16.2	-	-	.31	.21	-	-	.86	.59	.31	.21	-	-	.003	-	.028	-	-	.0034	.0039	-
726	Au	11	2	111	14.8	13.3	.133	.120	.32	.29	1.13	1.02	.34	.31	.27	.24	-	-	-	-	-	-	-	-	.0044	-
728	As	12	1	137	18.9	13.8	.101	.074	.55	.40	1.38	0.99	1.51	1.10	.30	.22	-	-	-	.0047	.0086	-	-	-	.0136	.0156
729	As, Cu	12	2	106	15.7	14.9	.058	.055	.47	.45	1.2	1.14	.38	.36	.45	.43	-	-	-	.011	.0070	-	-	-	.0400	.014
731	C, A	13	1	113	10.9	9.7	.150	.133	.36	.32	1.50	1.33	.46	.41	.44	.39	-	.017	.004	-	.0092	-	-	.0044	.0068	-
738	Cu	15	2	137	6.0	4.4	.146	.107	.33	.24	1.10	0.81	.26	.19	.19	.14	-	-	-	-	-	-	-	.0043	-	-
741	Cu	16	2	43	8.4	19.4	-	-	.168	.39	-	-	.062	.144	-	-	-	-	-	-	.024	-	-	-	-	-
742	Cu	16	3	41	10	24.3	-	-	.18	.44	-	-	-	-	.137	.34	-	-	-	-	-	-	-	-	-	-
743	Cu	17	1	43	9.6	22.2	-	-	.156	.36	-	-	.120	.28	-	-	-	-	-	-	-	-	-	-	-	-
747	Cu	18	2	59	5.8	10.0	.028	.048	.23	.39	.45	.77	.056	.096	-	-	-	-	-	-	-	-	-	-	-	-
776	Cu, Au	19	3	135	13.3	9.8	.033	.024	.29	.22	.73	.54	-	-	.084	.06	-	-	-	-	-	-	-	-	-	-
779	C, As	20	3	333	64.3	19.3	.071	.021	1.16	.35	2.22	.67	-	-	-	-	-	-	-	-	-	-	-	.0052	.0052	-
780	Rs	21	1	318	28.2	8.9	.029	.009	.59	.185	1.12	.35	.59	.185	.152	.05	-	.029	.006	-	.010	-	-	.0039	.0069	-
781	R, Cu	21	2	244	9.2	3.8	.053	.022	.34	.14	1.21	.50	.105	.043	.10	.04	-	-	-	-	-	-	-	.0042	-	-
785	Cu, C	22	3	77	10.3	13.3	-	-	.29	.38	.58	.75	-	-	-	-	-	-	-	-	.0033	-	-	-	-	-
786	Cs	23	1	43	9.6	22.2	-	-	.22	.51	.34	.79	.41	.95	-	-	-	-	-	-	-	-	-	-	-	-
787	Cu	23	2	52	6.4	12.2	.046	.088	.36	.69	.84	1.61	.22	.42	.30	.58	-	-	-	-	-	-	-	-	-	-
789	Cu	24	1	35	5.6	16.1	.040	.119	.29	.86	1.00	3.00	.17	.50	.14	.42	-	-	-	-	-	-	-	-	-	.027
791	As	24	3	269	44.4	16.5	-	-	.61	.23	1.08	.44	-	-	-	-	-	-	-	-	-	-	-	-	.0052	-
793	A, R, C	25	2	276	13.1	4.7	.110	.040	.56	.20	2.04	.74	.184	.067	.66	.24	-	.023	.006	-	.0090	-	-	-	-	-
798	Cs, As, R	27	1	242	21.8	9.0	.083	.034	.63	.26	1.31	.54	.41	.17	.092	.04	-	-	-	-	.0039	-	-	-	-	-
799	Ru	27	2	229	13.7	6.0	.050	.022	.30	.13	1.35	.59	.038	.017	.23	.10	-	.017	-	-	-	-	-	-	-	-
800	R	27	3	237	15.6	6.6	.049	.021	.28	.12	1.20	.51	-	-	.35	.15	-	.017	-	-	-	-	-	-	-	-
926	R	28	1	127	11.7	9.2	-	-	.17	.13	.33	.26	.127	.100	-	-	-	-	-	-	-	-	.008	-	-	-
927	Ru, Cu	28	2	134	9.8	7.3	.029	.022	.24	.18	.46	.34	.064	.048	.093	.07	-	-	-	-	-	-	-	-	-	-
931	Cu	29	3	58	5.4	9.4	-	-	-	-	-	-	-	-	.20	.35	-	-	-	-	-	-	-	-	-	-
934	A	30	3	135	18.4	13.6	-	-	.32	.24	.41	.30	-	-	.082	.06	.048	.015	-	-	-	.0134	-	-	.0035	-

*Periods classified according to direction and type of flow
First letter denotes predominant direction of flow as follows:
R - south and south-southwest, from Rubbertown
C - west-southwest through north-northwest, minimum trajectory over Louisville urban area
A - north through south-southeast, trajectory over Louisville urban area, excluding Rubbertown
Second letter denotes type of flow as follows:
u, unstable
s, stable
none, moderate or not specified

Table 3-37. RANK CORRELATION COEFFICIENTS BETWEEN SUSPENDED PARTICULATE CONSTITUENT CONCENTRATIONS AT STATION 1 - APRIL 1956

	Total	Organic	Mn	Pb	Fe	Cu	Zn	Cd*	Ni*
Total	-	+0.73 (35)	+0.28 (23)	+0.60 (34)	+0.62 (29)	+0.13 (26)	-0.04 (24)	-0.35 (12)	+0.02 (12)
Organic	+0.73 (35)	-	+0.25 (23)	+0.61 (34)	+0.32 (29)	+0.50 (26)	+0.08 (24)	-0.19 (12)	-0.03 (12)
Mn	+0.28 (23)	+0.25 (23)	-	+0.49 (23)	+0.66 (23)	+0.47 (20)	+0.44 (20)	-0.38 (8)	+0.20 (9)
Pb	+0.60 (34)	+0.61 (34)	+0.49 (23)	-	+0.59 (29)	+0.53 (26)	+0.31 (23)	+0.14 (12)	-0.26 (12)
Fe	+0.62 (29)	+0.32 (29)	+0.66 (23)	+0.59 (29)	-	+0.05 (23)	+0.43 (21)	+0.26 (11)	+0.22 (10)
Cu	+0.13 (26)	+0.50 (26)	+0.47 (20)	+0.53 (26)	+0.05 (23)	-	+0.24 (19)	+0.23 (9)	+0.31 (11)
Zn	-0.04 (24)	+0.08 (24)	+0.44 (20)	+0.31 (23)	+0.43 (21)	+0.24 (19)	-	+0.41 (8)	+0.43 (9)
Cd*	-0.35 (12)	-0.19 (12)	-0.38 (8)	+0.14 (12)	+0.26 (11)	+0.23 (9)	+0.41 (8)	-	-0.37 (6)
Ni*	+0.02 (12)	-0.03 (12)	+0.20 (9)	-0.26 (12)	+0.22 (10)	+0.31 (11)	+0.43 (9)	-0.37 (6)	-

Upper figure in each box is rank correlation coefficient between number of concurrently determined concentrations given by lower parenthetical figure.

* Correlations shown between Ni and Cd and other constituents are doubtful indicators. An alternate method of computing rank correlation coefficients is to assign a rank equal to the average rank of the missing values to each missing value. The coefficients obtained by this alternate method between total concentrations and Cd and Ni are +0.43 and +0.40 respectively.

Table 3-38. RANK CORRELATION COEFFICIENTS BETWEEN RELATIVE SUSPENDED PARTICULATE CONSTITUENT CONCENTRATIONS AT STATION 1 - APRIL 1956

	Organic	Mn	Pb	Fe	Cu	Zn	Cd	Ni
Organic	-	+0.40 (23)	+0.75 (34)	+0.30 (29)	+0.60 (26)	+0.57 (24)	-0.29 (12)	+0.34 (12)
Mn	+0.40 (23)	-	+0.67 (23)	+0.88 (23)	+0.73 (20)	+0.76 (20)	+0.68 (8)	+0.87 (9)
Pb	+0.75 (34)	+0.67 (23)	-	+0.69 (29)	+0.55 (26)	+0.76 (23)	+0.30 (12)	+0.19 (12)
Fe	+0.30 (29)	+0.88 (23)	+0.69 (29)	-	+0.39 (23)	+0.8° (21)	+0.61 (11)	+0.84 (10)
Cu	+0.60 (26)	+0.73 (20)	+0.55 (26)	+0.39 (23)	-	+0.56 (19)	+0.37 (9)	+0.51 (11)
Zn	+0.57 (24)	+0.76 (20)	+0.76 (23)	+0.82 (21)	+0.56 (19)	-	+0.73 (8)	+0.73 (9)
Cd	-0.29 (12)	+0.68 (8)	+0.30 (12)	+0.61 (11)	+0.37 (9)	+0.73 (8)	-	+0.49 (6)
Ni	+0.34 (12)	+0.87 (9)	+0.19 (12)	+0.84 (10)	+0.51 (11)	+0.73 (9)	+0.49 (6)	-

Upper figure in each box is rank correlation coefficient between number of concurrently determined relative concentrations given by lower parenthetical figure.

Table 3-39. COMPOSITION OF SELECTED SUSPENDED PARTICULATE SAMPLES FOR VARIOUS GROUPINGS AT STATION 1 - APRIL 1956 (AVE. CONC. IN $\mu g/m^3$*)

Group (a)		Total weight	Organic	Mn	Pb	Fe	Cu	Zn
All samples (35)	Conc.	142	16.1	0.051	0.39	0.92	0.35	0.18
	Percent	100	11.3	0.036	0.27	0.64	0.25	0.13
	Grouped by time sample was collected							
Period 1 (11) (2400-0800)	Conc.	130	15.4	0.056	0.39	0.88	0.79	0.17
	Percent	100	11.8	0.043	0.30	0.68	0.61	0.13
Period 2 (12) (0800-1600)	Conc.	141	10.4	0.064	0.33	1.05	0.18	0.23
	Percent	100	7.4	0.045	0.23	0.75	0.13	0.16
Period 3 (12) (1600-2400)	Conc.	155	22.5	0.035	0.44	0.83	0.12	0.14
	Percent	100	15.0	0.023	0.29	0.55	0.079	0.093
	Grouped by direction of airflow (from)**							
Rubbertown (6)	Conc.	232	18.0	0.040	0.35	1.12	0.59	0.16
	Percent	100	7.8	0.017	0.15	0.48	0.26	0.071
Non-Urban areas (13)	Conc.	62	7.9	0.041	0.26	0.61	0.15	0.16
	Percent	100	12.8	0.067	0.42	0.99	0.24	0.25
Other Urban areas (6)	Conc.	153	23.6	0.059	0.44	0.87	0.67	0.17
	Percent	100	15.4	0.038	0.29	0.57	0.81	0.19
	Grouped by total particulate concentration							
High (12)	Conc.	260	26.7	0.056	0.58	1.42	0.53	0.13
	Percent	100	10.3	0.022	0.22	0.55	0.15	0.068
Medium (11)	Conc.	129	14.6	0.070	0.35	0.91	0.52	0.22
	Percent	100	11.3	0.054	0.27	0.70	0.40	0.17
Low (12)	Conc.	49	7.9	0.029	0.24	0.47	0.14	0.14
	Percent	100	16.3	0.059	0.50	0.98	0.28	0.28

* Sample concentrations below detectable limit assigned values as follows: Mn, .019; Pb, .10; Fe, .24; Cu, .040; and Zn, .054.

** Periods of mixed air flow eliminated.

(a) Parenthetical numbers indicate number of samples.

Table 3-40. ODOR THRESHOLDS DETERMINED BY HUMAN REACTION FOR MATERIALS IN THE LOUISVILLE AIR

Panelist No.	Odor thresholds (ppb by volume)														
	Acrylonitrile			Chloroprene[a]			Creosol (creosote)			Gasoline			Styrene		
	Geo. mean	Run 1	Run 2	Geo. mean	Run 1	Run 2	Geo. mean	Run 1	Run 2	Geo. mean	Run 1	Run 2	Geo. mean	Run 1	Run 2
1	940	1080	810	27	27	27				4940	4940	4940	14	14	13
2	2130	2100	2170	27	27	27	45	54	37	2690	3220	2250	13	13	13
3	1020	1230	840	27	27	27	30	37	24	2250	2250	2250	15	17	13
4	1810	1770	1850	27	27	27	24	24	24	6010	7320	3940	9	8	9
5	1940	1990	1900	16	13	19	30	24	37	2690	3220	2250	16	18	14
6	1440	1180	1770	16	13	19	37	37	37	2250	2250	2250	11	9	13
7	1770	1770	1770				37	37	37	4940	4940	4940	25	21	30
8				27	27	27							20	20	20
9	1680	1600	1770	27	27	27	17	17	17	2250	2250	2250	11	13	10
10							37	37	37				24	20	30
11	1500	1990	1130				30	37	24	3990	4940	3220	14	13	14
12													45	46	43
13	1810	1690	1930										23	23	23
14													25	24	26
15				27	27	27	37	37	37	1830	2250	1490			
16				33	27	43									
17				27	27	27									

a. Polychloraprene aqueous suspension (neoprene liquid latex).

Table 3-41. ODOR THRESHOLDS FOR CERTAIN MATERIALS IN THE LOUISVILLE AIR

Pollutant	Odor Threshold Concentration (ppb)					Standard geometric deviation
	Median	Geom. mean		Range		
				Minimum	Maximum	
Acrylonitrile	1720	1560		940	2130	1.4
Chloroprene [a]	27	25		16	33	1.3
Creosol	34	31		17	45	1.3
Gasoline	2690	3120		1830	6010	1.3
Phenol	46	43				
Styrene	16	17		9	45	1.4
Toluene	103*			21	510	1.4

* Only data on range available. Value is geometric mean of minimum and maximum values.

a. Polychloroprene aqueous suspension (neoprene liquid latex).

Table 3-42. NUMBER OF DAYS ON WHICH OBSERVERS REPORTED VISIBLE DUSTINESS, IRRITATION. OR ODORS; BY MONTH - NOV. 1956 - MAY 1957 (212 DAY PERIOD)

Area	Visible dustiness								Odor								Irritation of eyes, nose, or throat							
	Total	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	Nov	Dec	Jan	Feb	Mar	Apr	May
1	44	0	23	0	6	6	9	0	46	0	24	0	7	6	9	0	44	0	22	0	7	6	9	0
2	5	1	0	1	1	0	2	0	9	2	2	0	1	2	2	0	3	0	0	0	1	1	1	0
3	1	0	0	0	0	1	0	0	4	1	0	0	1	2	0	0	3	1	1	0	0	1	0	0
4	6	1	0	2	1	1	1	0	21	0	0	7	4	3	5	2	8	0	0	4	2	1	1	0
5	14	3	0	1	0	3	4	3	17	2	0	3	1	3	5	3	12	0	0	1	1	2	5	3
6	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	4	4	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	2	1	0	0	1	0	0	0	9	1	3	1	3	1	0	0	4	0	2	0	0	1	0	1
9	3	0	2	0	0	1	0	0	8	2	3	0	0	1	2	0	7	4	2	0	0	0	1	0
10	15	0	0	0	3	8	4	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3	0	0
11	5	0	0	0	2	1	2	0	1	0	0	0	0	0	1	0	2	0	0	0	0	1	1	0
12	4	1	0	1	0	1	1	0	6	1	3	0	0	1	1	0	8	0	3	2	0	2	1	0
13	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
14	45	9	16	9	7	3	1	0	73	9	23	22	8	5	6	0	52	15	10	18	6	3	0	0
15	48	2	20	20	0	2	4	0	66	2	27	25	0	6	6	0	43	4	17	15	0	3	4	0
16	10	1	0	1	1	3	3	1	25	6	0	1	0	11	3	4	36	11	0	3	1	11	7	3
17	0	0	0	0	0	0	0	0	12	0	0	4	2	5	1	0	1	0	0	0	1	0	0	0
18	6	4	0	0	2	0	0	0	11	8	0	0	2	1	0	0	9	7	0	0	2	0	0	0
19	19	1	6	5	1	3	3	0	27	5	4	8	2	4	4	0	8	4	0	2	0	1	1	0
20	1	0	0	0	0	1	0	0	9	0	0	0	1	4	2	2	2	0	0	0	0	1	1	0
21	2	0	0	0	0	2	0	0	2	0	0	0	0	1	1	0	9	7	0	0	0	1	1	0
22	99	19	31	4	6	18	7	14	57	6	3	4	6	16	8	14	60	12	1	2	5	18	8	14
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
24	1	0	0	0	0	1	0	0	3	2	0	0	0	0	1	0	1	0	0	0	0	0	1	0
25	2	1	0	0	0	0	1	0	3	1	0	0	0	1	1	0	1	0	0	0	0	1	0	0
26	1	0	0	0	0	1	0	0	12	1	0	0	1	4	3	3	2	0	0	0	0	2	0	0
27	2	0	2	0	0	0	0	0	8	0	5	0	1	2	0	0	7	0	5	0	0	2	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	6	0	0	0	4	2	0	0	14	5	3	1	3	2	0	0	10	3	3	0	2	2	0	0
30	4	2	0	0	0	1	0	1	17	0	0	0	1	11	1	4	4	0	0	0	2	0	0	2
31	1	0	0	0	1	0	0	0	3	0	0	0	0	0	3	0	1	0	0	0	0	0	1	0
Total	346	46	100	44	35	60	42	19	468	58	100	76	44	92	65	33	346	72	66	47	30	63	44	24

Table 3-43. COMPARISON OF NUMBERS OF ODOR AND IRRITATION OBSERVATIONS WITH SULFUR DIOXIDE PEAK CONCENTRATION, FEB 15 - MAY 31, 1957*

Time of day	Number of positive reports		Total number of reports		Percent positive	
	$SO_2 < 0.1$ppm	$SO_2 \geq 0.1$ppm	$SO_2 < 0.1$ppm	$SO_2 \geq 0.1$ppm	$SO_2 < 0.1$ppm	$SO_2 \geq 0.1$ppm
ODOR						
Total	74	31	1584	441	4.7	7.0
06-0800	26	16	459	216	5.7	7.4
16-1800	15	5	558	117	2.7	4.3
20-2200	33	10	567	108	5.8	9.3
IRRITATION						
Total	75	24	1584	441	4.7	5.4
06-0800	25	14	459	216	5.4	6.4
16-1800	14	4	558	117	2.5	3.4
20-2200	36	6	567	108	6.3	5.5

*Odor and irritation reports are from students in areas 14, 15, 16, 18, 19, 20, 22, 23, and 24.

Sulfur dioxide concentrations were measured at 37th and Broadway (Station B) and are peak values for the time period.

Table 3-44. DUSTFALL IN LOUISVILLE, BY STATION AND MONTH; 1956
(TONS/SQ. MI./30 DAYS - TOTAL WATER-SOLUBLE AND INSOLUBLE)

Sampling location	Mean (rounded)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	40	27	42	50	32	35	33	40	-	42	26	70	-
2	28	22	-	-	32	27	29	29	28	29	-	-	-
3	34	29	73	42	35	27	-	33	48	32	14	30	10
4	21	16	37	25	20	21	17	24	17	23	15	19	16
5	33	25	46	46	35	22	48	31	28	22	21	47	26
6	20	17	19	30	32	22	-	15	14	20	15	18	15
7	15	12	-	-	-	18	-	15	16	-	88	20	-
8	28	22	39	48	27	20	14	26	19	34	-	41	21
9	29	-	51	36	30	27	22	31	27	21	15	27	-
10	21	-	-	-	-	20	22	30	23	21	16	13	-
11	39	-	39	53	40	-	53	36	37	35	19	43	-
12	42	39	69	55	48	43	32	36	40	40	34	40	24
13	39	27	46	51	128	29	37	28	25	29	13	31	19
14	25	32	30	33	21	22	29	26	23	25	19	22	19
15	37	75	-	-	35	34	23	59	-	33	13		24
16	17	14	23	22	21	18	17	22	10	20	9	15	13
17	34	34	47	50	27	42	22	40	32	34	31	19	-
18	28	21	28	35	27	32	24	-	-	-	-	-	-
19	18	14	-	27	24	15	17	17	15	22	15	16	-
20	25	12	30	30	27	55	37	11	22	28	11	17	14
21	24	24	-	-	-	-	-	-	-	-	-	—	-
22	26	17	-	37	48	28	18	22	25	29	14	28	19
23	179	-	-	-	182	155	227	251	196	178	67	-	-
24	26	-	-	-	-	-	-	31	20	38	18	18	29
Mean*	29	25	41	39	36	28	27	29	25	29	17	30	19

* Does not include location 23 because data available only for part of year for this location where dustfall is often very high and thus unduly influence monthly variation of average for all stations.

Dashes indicate data not available.

Table 3-45. VARIATION IN COMPOSITION OF SETTLED DUST WITH LOCATION

Number of sampling stations	Number of samples	Average distance to industry number 8 (miles)	Calcium carbonate	Calcium magnesium carbonate	Calcium hydroxide	Calcium sulfate	Silicon dioxide (quartz)	Unknown	Calcium carbonate / Silicon dioxide
3	6	0.5	60.0	8.3	0.8	0.8	28.3	1.6	2.1
3	6	1.1	25.0	10.8	1.7	0.8	55.0	6.7	0.46
4	7	2.2	22.0	8.6	0.0	0.0	65.0	4.3	0.34

Collected on greased glass plates; x-ray diffraction analysis.

Table 3-46. SPRING TENSION MEASURED AT AIR SAMPLING STATIONS TO DETERMINE METAL DETERIORATION, FEB - OCT, 1956 (DATA ARE IN POUNDS TENSION EXERTED BY SPRINGS AT A FIXED SPRING LENGTH)

Date		Spring location												
		Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Control
		In-side*	Out-side**	In-side	Out-side	In-side	Out-side	In-side	Out-side	In-side	Out-side	In-side	Out-side	
February	1	4.25	4.5	4.00	4.25	4.25	4.25	4.00	4.25	4.25	4.50	4.50	4.50	4.25
Feb.	14	4.25	4.5	4.25	4.25	4.5	4.25	4.25	4.5	4.5	4.25	4.50	4.50	4.25
Feb.	28	4.25	4.50	4.50	4.25	4.25	4.25	4.25	4.50	4.25	4.25	4.50	4.25	4.25
March	14	4.00	4.25	4.25	4.25	4.25	4.00	4.25	4.25	4.25	4.00	4.25	4.00	4.25
March	28	4.0	4.25	4.5	4.25	4.5	4.0	4.5	4.25	4.25	4.25	4.25	4.0	4.0
April	11	4.25	4.0	4.25	4.0	4.25	4.0	4.0	4.25	4.25	4.0	4.25	4.0	4.0
May	9	4.25	3.75	4.25	4.0	4.25	3.75	4.25	3.75	4.25	3.75	4.25	3.75	4.25
May	23	4.25	3.50	4.25	3.75	4.25	3.5	4.0	3.50	4.25	3.50	4.25	Broke	4.0
June	7	4.25	3.5	4.25	3.75	4.25	3.5	4.25	3.25	4.25	3.5	4.25		4.0
June	27	4.25	3.25	4.5	3.75	4.25	3.25	4.25	3.25	4.25	3.25	Broke		4.25
July	18	4.25	3.0	4.25	3.5	4.0	3.0	4.25	3.0	4.25	3.0			4.0
August	5	4.25	Broke	4.25	Broke	4.0	3.0	4.0	3.0	4.25	2.75			4.0
August	14	4.0		4.0		3.75	2.75	4.0	2.75	4.25	2.75			4.0
Aug.	30	4.0		4.25		Broke	2.75	4.0	2.75	4.0	2.5			4.0
Sept.	12	4.0		4.25			2.75	4.0	3.0	4.0	2.75			4.0
October	1	4.0		4.25			2.5	4.0	2.5	4.0	2.5			4.0
Percent loss in tension per 30 days			5.8		3.1		5.0		5.0		5.4		5.1	0.7

* Inside air sampling shelter

** Outside air sampling shelter

Table 3-47. AIR-BORNE BACTERIA CONCENTRATIONS AS DETERMINED BY SETTLING PLATE, AND SLIT, AND TANGENTIAL JET SAMPLERS,* STATION 1, NOV., 1956 - AUG., 1957

Dates	Time of day samples collected	Settling plate sampler (No. of bacteria carrying particles settling per min. of exposure)			Slit sampler (No. of bacteria carrying particles on agar plate per cu. ft. of air sampled)			Tangential jet sampler (No. of bacteria collected per cu. ft. of air sampled)		
		Mean	Range		Mean	Range		Mean	Range	
			Low	High		Low	High		Low	High
Nov. - Aug. Total	08-1600	2.78	0.0	16.9	4.60	0.1	18.1	50.3	1.0	370.7
Nov. 12-16, '56	08-1600	4.14	0.1	13.4	7.32	0.6	18.1	105.5	1.1	370.7
Nov. 12, '56	08-1100	4.6	1.9	8.7	8.6	5.9	13.2	132.6	77.0	189.6
	13-1600	7.2	3.9	11.4	8.1	2.5	13.0	126.9	83.3	186.6
Nov. 13, '56	08-1100	3.2	1.8	5.6	8.0	3.0	13.7	203.3	203.3	203.3
	13.1600	4.3	2.4	8.7	10.2	4.2	16.1	171.1	64.7	303.2
Nov. 14, '56	08-1199	5.5	3.7	8.3	8.0	4.6	11.9	169.4	122.2	279.6
	13-1600	7.2	4.5	11.2	8.8	6.0	14.9	209.7	96.1	370.7
Nov. 15, 156	08-11-0	7.3	3.5	13.4	11.2	5.5	18.1	193.1	101.2	308.2
	13-1600	1.3	0.6	2.8	-	-	-	30.3	9.3	100.1
Nov. 16, '56	08-1100	0.4	0.1	1.1	1.1	0.6	1.9	9.6	9.6	9.6
	13-1600	0.4	0.1	0.8	1.9	0.8	4.0	8.6	1.1	32.0
Feb. 11-15 '57	08-1600	1.44	0.0	7.2	2.87	0.1	12.7	17.7	1.0	49.2
Feb. 11, '57	08-1100	0.4	0.0	0.7	1.2	0.3	4.9	-	-	-
	13-1600	0.2	0.1	0.5	0.9	0.2	1.2	-	-	-
Feb. 12, '57	08-1100	0.8	0.2	1.3	3.3	1.3	5.0	-	-	-
	13-1600	3.4	1.4	7.2	3.3	2.3	5.5	27.3	9.2	49.2
Feb. 13, '57	08-1100	0.4	0.0	1.2	1.9	0.7	5.1	-	-	-
	13-1600	0.5	0.2	1.4	1.4	0.5	3.5	8.0	1.0	27.3
Feb. 14, '57	08-1100	0.5	0.2	0.9	1.2	0.9	2.0	-	-	-
	13-1600	0.6	0.1	1.3	1.2	0.1	2.0	-	-	-
Feb. 15, '57	08-1100	3.4	2.1	4.8	6.3	2.3	12.7	-	-	-
	13-1600	4.2	1.6	6.1	8.0	5.4	10.6	-	-	-
May 13-17, '57	08-1600	2.00	0.0	7.8	4.07	0.4	16.0	30.8	1.0	188.9
May 13, '57	08-1100	2.1	1.0	3.1	3.6	1.6	8.0	16.2	7.7	44.0
	13-1600	1.7	0.8	2.8	3.6	0.9	5.3	17.5	6.0	44.8
May 14, '57	08-1100	0.8	0.0	2.7	5.9	1.0	16.0	134.3	7.9	188.9
	13-1600	0.5	0.2	1.5	2.0	1.2	3.9	10.3	1.0	19.4
May 15, '57	08-1100	2.4	1.5	4.0	5.0	0.4	7.0	19.9	12.2	30.9
	13-1600	3.0	1.4	3.9	5.3	1.8	10.5	22.3	7.0	35.7
May 16, '57	08-1100	3.0	1.3	7.8	5.5	1.8	11.7	24.2	8.8	24.2
	13-1600	2.5	1.1	5.2	4.6	2.0	9.7	21.8	4.8	65.5
May 17, '57	08-1100	1.9	0.4	4.4	3.1	0.8	8.4	13.5	5.8	31.4
	13-1600	2.1	0.3	7.2	2.1	0.4	6.3	27.7	5.3	23.0
Aug. 5-9, '57	08-1600	3.55	0.4	16.9	4.14	0.6	12.7	47.3	3.4	202.0
Aug. 5, '57	08-1100	3.5	1.8	5.3	4.1	1.5	7.6	59.1	26.8	93.0
	13-1600	4.0	2.4	7.1	4.1	2.0	6.6	71.1	55.8	100.9
Aug. 6, '57	08-1100	7.1	1.7	10.4	6.7	1.9	10.6	68.2	26.5	111.3
	13-1600	8.0	3.2	16.9	6.6	3.8	8.7	97.3	49.9	102.9
Aug. 7, '57	08-1100	4.0	1.9	8.2	4.5	2.6	7.3	40.4	22.0	61.0
	13-1600	4.2	2.2	5.5	5.0	1.8	8.4	55.9	30.3	95.0
Aug. 8, '57	08-1100	1.4	0.9	2.2	2.1	0.6	4.4	19.8	5.9	36.4
	13-1600	1.0	0.6	1.4	2.2	0.9	3.7	20.2	7.8	47.8
Aug. 9, '57	08-1100	1.0	0.4	2.7	3.9	1.3	12.7	13.5	3.4	33.8
	13-1600	1.3	0.5	1.9	2.2	1.4	3.2	27.7	14.7	292.0

* Total counts after 48 hours at 37°C

Table B-1. PAINT FACTORS FOR PETROLEUM STORAGE TANKS VAPOR LOSS CALCULATIONS.[40]

Tank color	Paint factor (F_p)
White	0.75
Aluminum	1.00
Gray	1.10
Black	1.25

Table B-2. LIQUID-SURFACE AND VAPOR SPACE TEMPERATURES FOR STORED PETROLEUM STOCK AT VARIOUS LOCATIONS IN THE UNITED STATES[40]

Location	t	t_1	t_2	T_1	T_2
USA Average	90	85	95	80	135
Pacific Coast	75	70	80	65	120
Atlantic, Gulf Coasts, and N. Middle West	95	90	100	85	140
Mid-Continent & Southwest	110	105	115	100	155

Table B-3. FACTORS FOR ESTIMATING LOSSES FROM OTHER THAN FIXED ROOF STORAGE TANKS

Tank type	Breathing loss	Filling loss
Fixed roof, pressure vent$>$ 2.5psig	B	0.75 F
Variable vapor space	0.1 B	0.75 F
Fixed roof, one open vent	1.5 B	F
Fixed roof, two open vents	2.0 B	F

The factors B and F are calculated from equations B-8 and B-10. Boiling loss calculations are unchanged.

Table B-4. DUST EMISSION FACTORS FOR VARIOUS COAL FIRED SPREADER STOKER UNITS

Overfire jets	Dust reinjection	$\frac{\text{Lbs. total solids}}{\text{Lb. coal fired}}$
No	No	0.11 - 0.66 A
No	Yes	0.17 - 1.00 A
Yes	No	0.09 - 0.63 A
Yes	Yes	0.11 - 0.66 A

Table B-5. SIZE OF PARTICLES EMITTED FROM VARIOUS TYPES OF COAL FIRED FURNACES

Firing Method	Mass median diam. microns (geometric means)	Standard geometric deviation	Percent by weight less than one micron
Underfeed stoker	20	3.9	3.0
Traveling grate	75	2.0	<0.01
Cyclone furnace	5	3.7	12.0
Spreader stoker	57	4.1	0.2
Pulverized coal	20	2.5	0.1

Table B-6. SIZE OF PARTICLES EMITTED FROM DOMESTIC AND COMMERCIAL COAL COMBUSTION DEVICES

Firing method	Carbon and tars ($<1\mu$)	Carbon and tars ($>1\mu$)	Ash ($>1\mu$)
Hand-fired furnaces	0.006	0.004	0.002
Stoker-fired furnaces or stoves	0.0025	0.0015	0.0015
Hand-fired stoves	0.014	0.010	0.003

REFERENCES

1. Yocum, J. E., Saslaw, J. M., Chapman, S., and Richardson, R. L. Summary Report on Research Investigations of Air Pollution in the Vicinity of Louisville, Ky. Report to Rubbertown Industrial Group. Battelle Memorial Institute. Columbus, Ohio. July, 1954.

2. Drinker, P., and Hatch, T. Industrial Dusts. 2nd Edition. Mc-Graw— Hill Book Co., Inc. New York. 1954. pp 123 - 165

3. Brief, R. S., and Drinker, P. A. Collection of integrated samples of gaseous effluents. A. M. A. Arch. Ind. Health 17:654. 1958.

4. Taylor, E., and Johnstone, H. F. Determination of the sulfur content of gases from boiler furnaces. Ind. Eng. Chem. Anal. Edition 1:197. 1929.

5. Johnstone, H. F. Reactions of sulfur compounds in boiler furnaces. Ind. Eng. Chem. 23:620. 1931.

6. Hughes, E. E. Final Report on the Participation of the National Bureau of Standards in the Study of Air Pollution in Louisville and Jefferson County. National Bureau of Standards Report No. 5628. U. S. Department of Commerce. Wash., D. C. Dec. 1957.

7. Schwartz, C. H., et. al. Report on Project No. 1881 - 782 for U. S. Public Health Service. U. S. Bureau of Mines. Pittsburgh. July 13, 1956.

8. Perry, J. H., Ed. Chem. Engrs. Handbook. 3rd Edition. McGraw - Hill Book Co., Inc. New York 1950. p 545.

9. Joint District, Federal, and State Project for the Evaluation of Refinery Emissions. Reports Nos. 1 Through 9. Los Angeles County Air Pollution Control District. July 1956 Through July 1958.

10. Perry, J. H., Ed. op. cit. p 1026

11. Perry, J. H., Ed. op. cit. p 1040

12. Tobe, J. E. President, Appalachian Coals, Inc. Personal communication to A. C. Stern,
12. Chief, Air Pollution Engineering Research, Public Health Service. Cincinnati, Jan. 13, 1958.

13. Bourne, R. W. Air Pollution Control Board of Jefferson County, Ky. personal Communication to D. M. Anderson, Public Health Service. January 21, 1959

14. Fuel Dealers, local. personal communications to Engineering Staff, Special Air Pollution Study, January 1957

15. Louisville Gas and Electric Co. Personal communication to Engineering Staff, Special Air Pollution Study. January 1957.

16. Second Technical and Administrative Report on Air Pollution Control in Los Angeles County. Los Angeles County Air Pollution Control District Annual Report. 1950 - 1951. p. 37.

17. Kentucky State Traffic Department. personal communication to Engineering Staff, Special Air Pollution Study. January 1957.

18. Kentucky State Highway Department. Personal communication to Engineering Staff, Special Air Pollution Study. January 1957.

19. Louisville Transit Co. personal communication to Engineering Staff, Special Air Pollution Study. January 1957.

20. Railroad Representatives (Pennsylvania R. R. Co., Southern Railway System, New York Central System, Baltimore and Ohio R. R. Co., Kentucky and Indiana Terminal R. R. Co., Monon R. R., Illinois Central R. R., and Louisville and Nashville R. R. Co.). personal communications to N. E. Schell, Resident Engineer, Special Air Pollution Study. February - March 1957.

21. Megonnel, W.H. Interstate Atmospheric Transport of Tracer Particles in the N. Y. - N.J. Metropolitan Area. Robert A. Taft Sanitary Engineering Center Technical Report A58-6. Cincinnati, Ohio January 1958.

22. The Stanford Fluorescent Particle Tracer Technique. An Operational Manual (Chemical Corps Research and Development Program Contract No. DA-18-064-cml-2564). Stanford University Department of Chemistry. June 1955

23. Shallenberger, W.H., and Stecker, E.J. Tracer technique in air pollution studies. in proceedings. 1954 Southern Industrial Waste Conference. Houston. April 1954.

24. Air Pollution Measurements of the National Air Sampling Network. Public Health Service Publ No. 637. November 1958. Superintendent of Documents. Wash. 25, D.C. $2.00

25. Standard Methods for the Examination of Water, Sewage, and Industrial Wastes. 10th Edition. Am. Pub. Health Assoc. New York. 1955, p 61.

26. Gelman, C. Estimation of water-soluble chlorides, sulfates, and nitrates in suspended atmospheric dusts. J. Air Pollution Control Assoc. 7:216-219. November 1957.

27. Hemeon, W.C.L., Haines, G.F., and Ide, H.M. Determination of haze and smoke concentrations by filter paper samplers. Air Repair 3:22. 1953.

28. Huges, E.E., and Gorden, R., Jr. Determination of acetylene in air in concentrations from 10 ppb. to 10 ppm. Anal. Chem. 31:94-98. January 1959.

29. Goldman, F.H., and Yagoda, H. Collection and estimation of traces of formaldehyde in air. Ind. Eng. Chem. Anal. Edition 15:377. 1943.

30. Saltzman, B.E. Colorimetric microdetermination of nitrogen dioxide in the atmosphere. Anal. Chem. 26:1949-1955 1954.

31. Haagen-Smit, A.J., and Fox, M.M. Phenolphthalin as a reagent for the determination of oxidant in air. Unpublished. April 12, 1954.

32. Smity, R.G., and Diamond, P. The microdetermination of ozone. Am. Ind. Hyg. Assoc. Quarterly 13:235-238. 1952.

33. Braverman, M.M., Hochheiser, S., and Jacobs, M.B. Colorimetric ultramicrodetermination of phenol in air. Am. Ind. Hyg. Assoc. Quarterly 18:132. 1957.

34. West, P.W., and Gaeke, G.C. Fixation of sulfur dioxide as disulfitomercurate (II) and subsequent colorimetric estimation. Anal. Chem. 28:1816-1817. 1956.

35. Nader, J.S. An odor evaluation apparatus for field and laboratory use. Am. Ind. Hyg. Assoc. J. 19:1-7. February 1958.

36. Markee, E.H., Jr. Relationships of an air quality measurement to meteorological parameters. Am. Ind. Hyg. Assoc. J. 20:50-55. February 1959.

37. Ezekiel, M. Methods of Correlation Analysis. 2nd Edition. John Wiley and Sons. New York. 1941

38. Blackmore, S.S. Dust emission control at Electromet. Ind. Wastes 3:73-78. May - June 1958.

39. The Air Over Louisville. Summary of a Joint Report by the Special Air Pollution Study of Louisville and Jefferson County, Kentucky, 1956 - 57. Robert A. Taft Sanitary Engineering Center. Cincinnati, Ohio. May, 1958. 57 pp.

40. Evaporation Loss of Petroleum from Storage Tanks. Paper presented at 32nd annual meeting of Am. Petroleum Institute, Chicago, Ill. November 1952.

41. Perry, J.H., Ed. op. cit. pp 483-489.

42. Perry, J.H., Ed. op. cit. p 341.

43. Perry, J.H., Ed. op. cit. p 291.

44. Perry, J.H., Ed. op. cit. Table 11, p 539.

45. Wohlers, H.C., and Bell, G.B. Literature Review of Air Pollution Concentrations--Preparation, Sampling, and Assay of Synthetic Atmospheres. SRI Project No. SU-1816. Stanford Research Institute. Menlo Park, Calif. November 30, 1956.

46. Committee on Air Pollution, Interim Report. Command 9011. Her Majesty's Stationary Office. London. 1953.

47. Meetham, A.R. Atmospheric Pollution Its Origin and Prevention. Pergamon Press. London. 1956.

48. Crumley, P.H., and Fletcher, A.W. The emission of sulfur gases from a domestic solid fuel appliance. J. Institute of Fuel (London) 30:608. 1957

49. Yeau, J.S., and Schnidman, L. Flue products of industrial fuels. Ind. Eng. Chem. 28:999. 1936.

50. Orning, A.A. Industrial sources of air pollution- electric power plants (coal fuel). Proceedings National Conference on Air Pollution. Public Health Service Publication No. 654. pp 155 - 160. 1959. Superintendent of Documents, Wash. 25, D.C. $1.75.

51. Myers, J.W., et. al. Calculation of Theoretical flame temperatures in furnaces. Trans. Am. Soc. Mechanical Engrs. 80:202. 1958.

52. Chemistry of Coal Utilization. Committee on Chemical Utilization of Coal, National Research Council. John Wiley and Sons, Inc. New York. 1945. p 1075.

53. Cave, G.A. Dusts and smokes in flue gases. Brit. Coal Utilization Research Assoc. Monthly Bull. 10:61. 1946.

54. Swengel, F.M. Correlation of data concerning spreader stokers and fly ash. Plant 6:46. October 1952.

55. Kaiser, E.R. Factors affecting dust emission from boiler furnaces. Proc. Air Pollution and Smoke Prevention Assoc. of America, 44th Annual Convention 1951. pp 65 - 74.

56. Marks, C.H., and Kaiser, E.R. Reducing Flue- Dust Emission from Small Industrial Boiler Plants. Bituminous Coal Research, Inc. Pittsburgh. August 1953.

57. Miller, C.E. What can the Small Plant Do About Fly Ash. Bituminous Coal Research, Inc. Pittsburgh. April, 1949.

58. Holton, W.C., and Engdahl, R.B. Methods of reducing dust emissions from a spreader-stoker-fired boiler furnace. Trans. Am. Soc. Mechanical Engr. 74:207. 1952.

59. Committee of Investigation, Chicago Asso. of Commerce. Smoke Abatement and Electrification of Railway Terminals in Chicago. Rand McNally and Co. Chicago. 1915. p 1143.

60. Evans, R., and Davenport, J. Analysis of combustion in flue gas. Ind. Eng. Chem. Anal. Edition 7:174. 1935.

61. Where much of the responsibility rests for poor heating and air pollution. Coal-Heat 51:8. April 1947.

62. Lammers., H.B. What a survey of heating and power plants will disclose in most cities. Coal-Heat 51:8. June 1947.

63. Recommendations for the abatement of smoke and atmospheric pollution. Coal-Heat 52:28. November 1947.

64. Kreisinger, H., Augustine, C.E., and Katz, S.H. Low Rate Combustion in Fuel Beds of Hand-Fired Furnaces. U.S. Bureau of Mines Tech. Paper 139. Pittsburgh, 1918.

65. Landers, W.S., and Parry, V.F. Domestic Storage of Subbituminous Lump Coal and its Performance in a Hand-Fired Furnace. U.S. Bureau of Mines Report of Investigation 3759. Pittsburgh. June 1949.

66. Yancey, H.F., et al. Burning Washington Coals on Different Types of Domestic Stokers in the Same Hot-Water Boiler; Comparison with Hand and Oil Firing. U.S. Bureau of Mines Bull. 475. Wash., D.C. 1949.

67. Monkhouse, A.C. Coal smoke - its nature and prevention. Chem. Ind. 68:1129. 1951.

68. Cleghorn, M.P., and Helfinstine, R.J. Use of Iowa Coals in Domestic Stokers. Iowa Eng. Experiment Station Bull. 144. Iowa State College. Ames, Iowa. 1939.

69. Meetham, A.R. Natural removal of air pollution from the atmosphere. Quarterly J. Royal Met. Soc. 76:359. 1950.

70. The Smog Problem in Los Angeles County. Stanford Research Institute. Menlo Park, Calif. 1954.

71. Magill, P. W., and Benoliel, R. W. Air pollution in Los Angeles County, Contribution of Combustion products. Ind. Eng. Chem. 44:1347. 1952.

72. Faith, W. L. Combustion and Smog. Air Pollution Foundation. Report No. 2. Los Angeles. September 1954.

73. Hall, E. L. Products of combustion of gaseous fuels. Proc. 2nd National Air Pollution Symposium. Pasadena, Calif. May 1952. p 84.

74. Tebbens, B. D., Thomas, J. F., and Mitsugi, M. Hydrocarbon synthesis in combustion. Arch. Ind. Health 13:567. 1956.

75. Connolly, T. J., and Nobe, K. The Formation of Oxides of Nitrogen in Gas-Fired Heaters. First Report of Air Pollution Studies. Report 55 - 27. Univ. of Calif. in Los Angeles, July 1955.

76. Lunde, K. E. Investigation of Air Pollution in the Vicinity of Portland, Oregon. Project No. S-1674. Stanford Research Institute. Menlo Park, Calif. October, 1956.

77. Churchill, H. V., Rowley, R. J., and Martin, L. N. Fluorine content of certain vegetation in a western Pennsylvania area. Anal. Chem. 20:69. 1948.

78. Technical and Administrative Report on Air Pollution Control in Los Angeles County. Los Angeles County Air Pollution Control District Annual Report. 1949 - 1950.

79. Magill, P. L., Hutchinson, D. H., and Stormes, J. M. Hydrocarbon constituents of automobile exhaust gases. Proc. 2nd National Air Pollution Symposium. Los Angeles. 1952. pp 71-83.

80. Hirschler, D. A., et. al. Particulate lead compounds in automobile exhaust gas. Ind. Eng. Chem. 49:1131. 1957.

81. Doyle, G. J. The formation of aerosols by irradiation of dilute auto exhaust. J. Air Pollution Control Asso. 8:23. May 1958.

82. Silverman, L. Experimental Test Methods. in Magill, P. L., et al. Eds. Air Pollution Handbook. McGraw-Hill Book Co., Inc. New York. 1956. pp 12 16.

83. Faith, W. L. op. cit. Tables 18 and 19. pp 46 - 47.

84. Rounds, F. G., et al. Some effects of engine - fuel variables on exhaust gas hydrocarbon content. J. Air Pollution Control Assoc. 5:109. August 1955.

85. Elliot, M. A. The composition of exhaust gases from diesel, gasoline, and propane powered motor exhaust. J. Air Pollution Control Assoc. 5:103. August 1955

86. Louisville Chamber of Commerce. Personal communications to Engineering Staff, Special Air Pollution Study. January 1957.

87. Bourne, R. W. Air Pollution Control Board of Jefferson County, Ky. personal communication to D. M. Anderson, Public Health Service. August 7, 1958.

88. Sax, N. Irving. Handbook of Dangerous Materials. Reinhold Publishing Co., New York. 1951.

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